The Abdus Salam International Centre for Theoretical Physics

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IAEA International Atomic Energy Agency

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Advanced Workshop on Evaluating, Monitoring and Communicating Volcanic and Seismic Hazards in East Africa

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InSAR fundamentals and Advanced Methods

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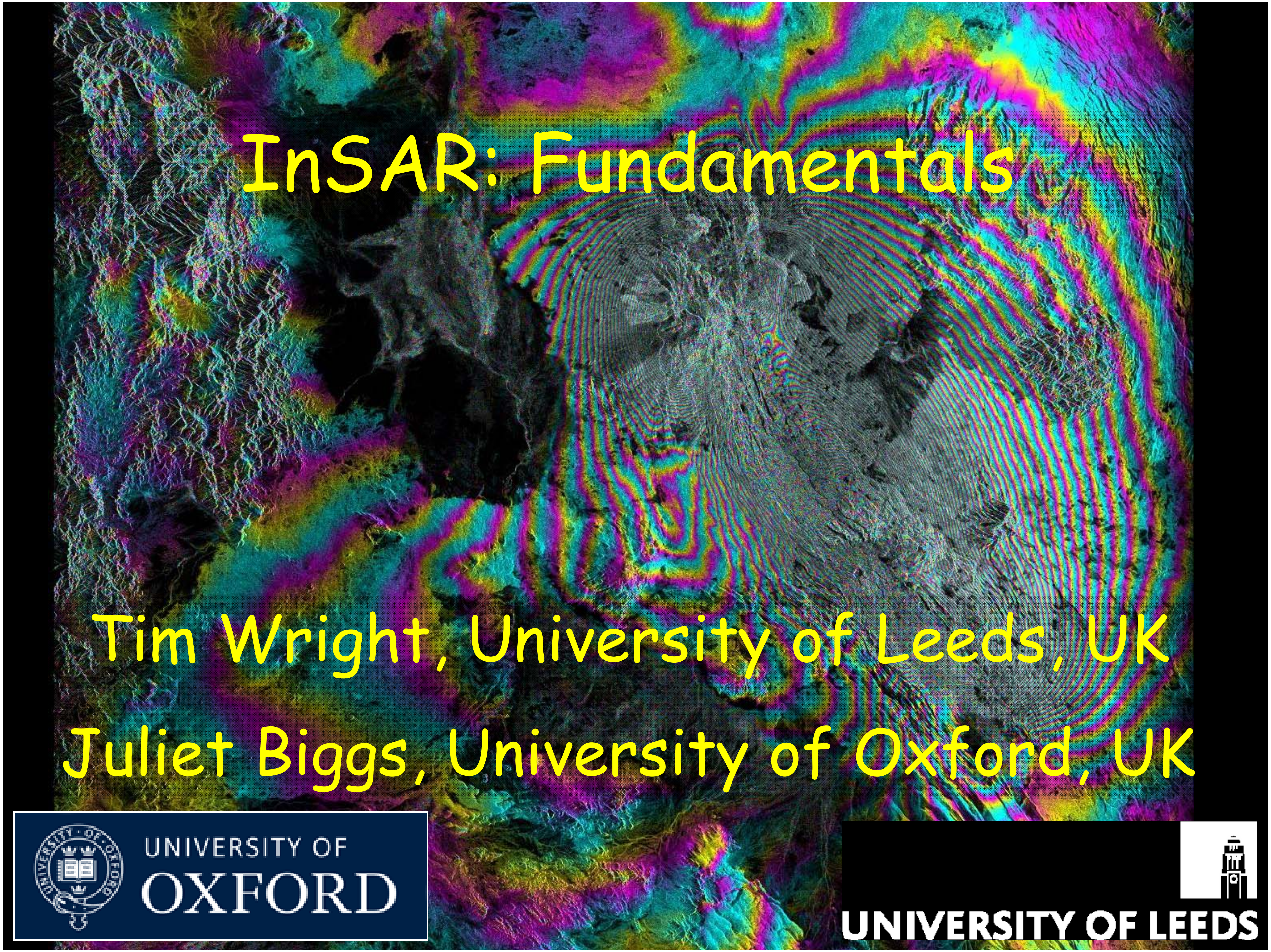
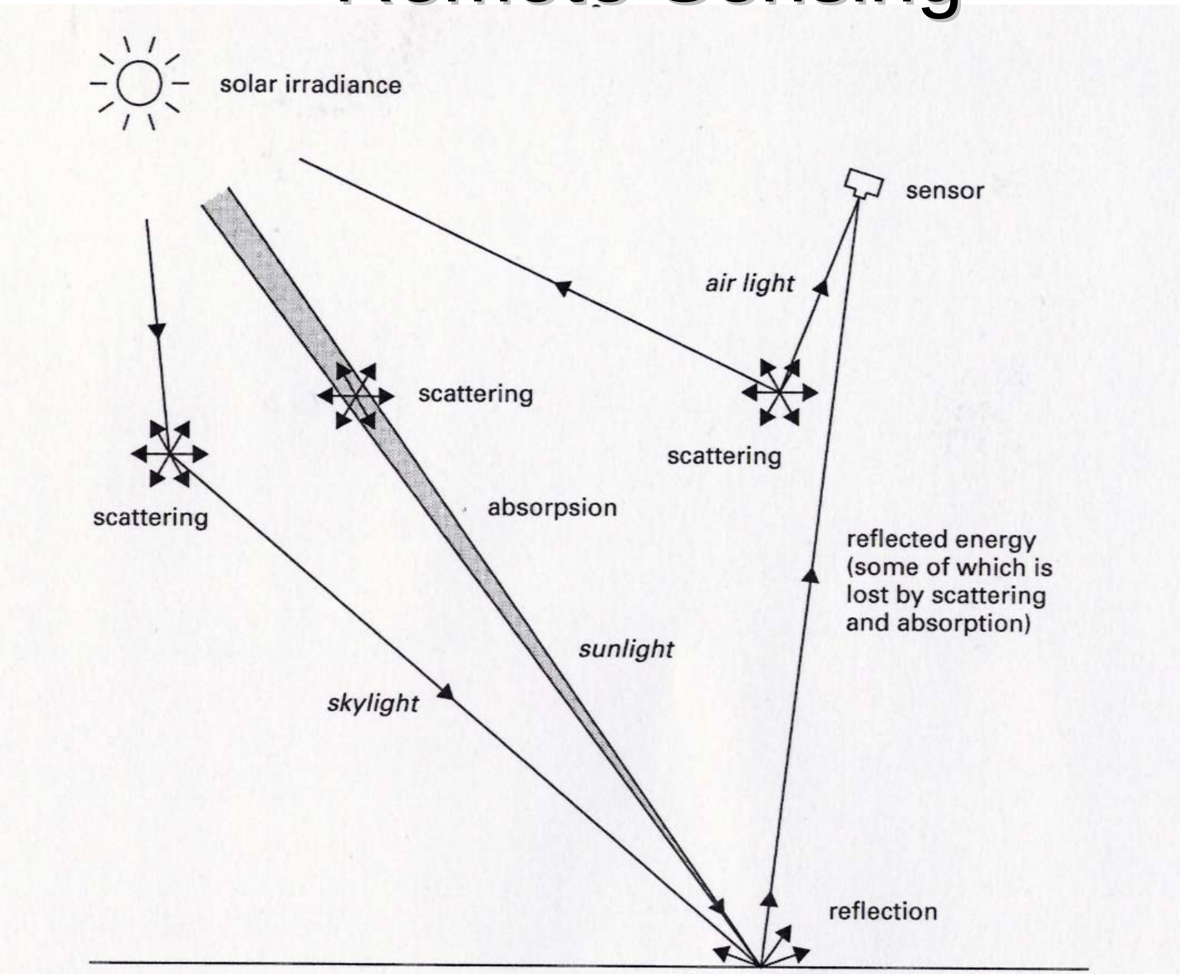

InSAR: Fundamentals
Tim Wright, University of Leeds, UK
Juliet Biggs, University of Oxford, UK
UNIVERSITY OF OXFORD
UNIVERSITY OF LEEDS

Outline

- Radar remote sensing
- InSAR – the basics
- Components of interferometric phase
- Some examples of seismic and volcanic deformation
- The Future

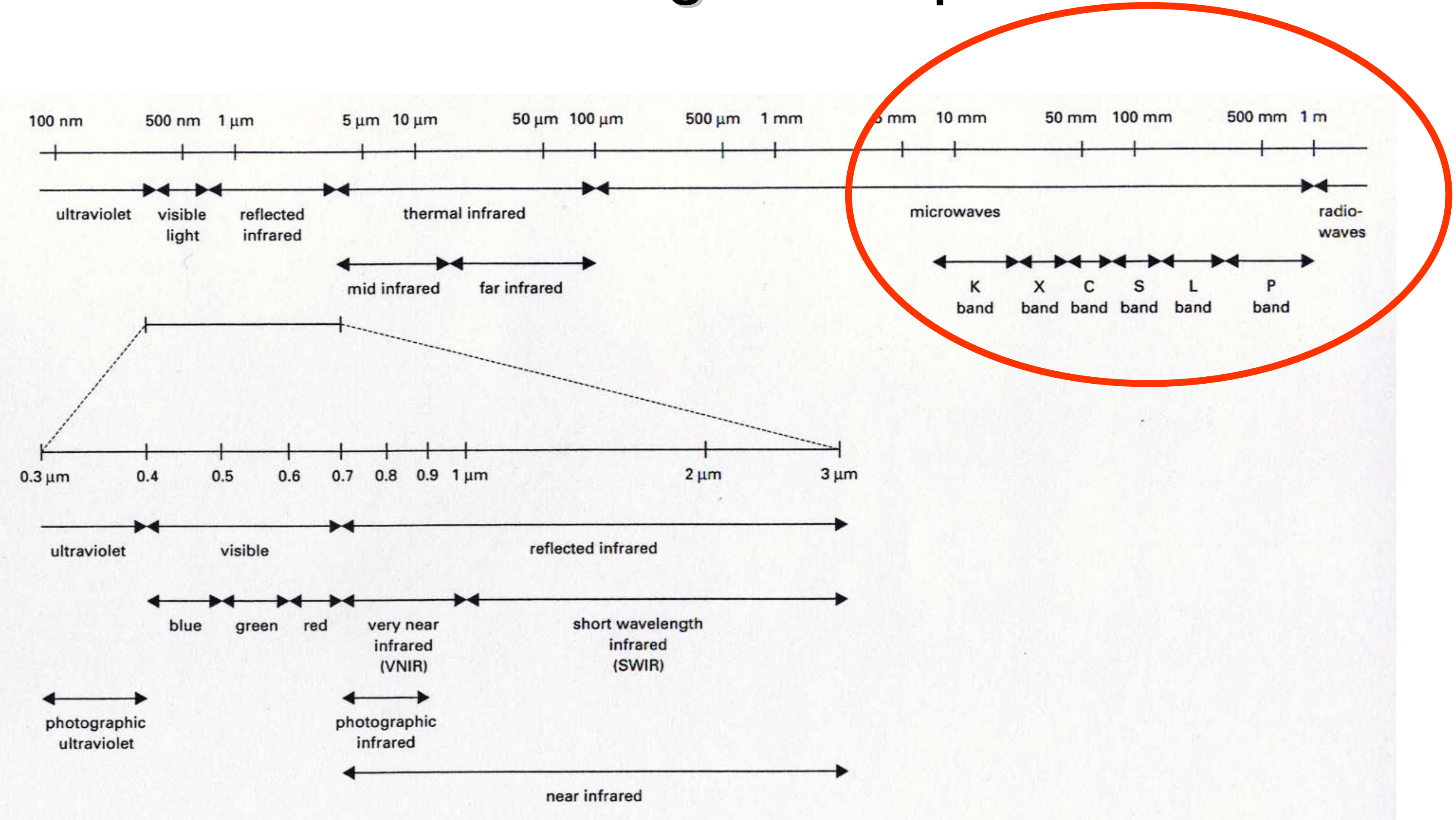
Remote Sensing



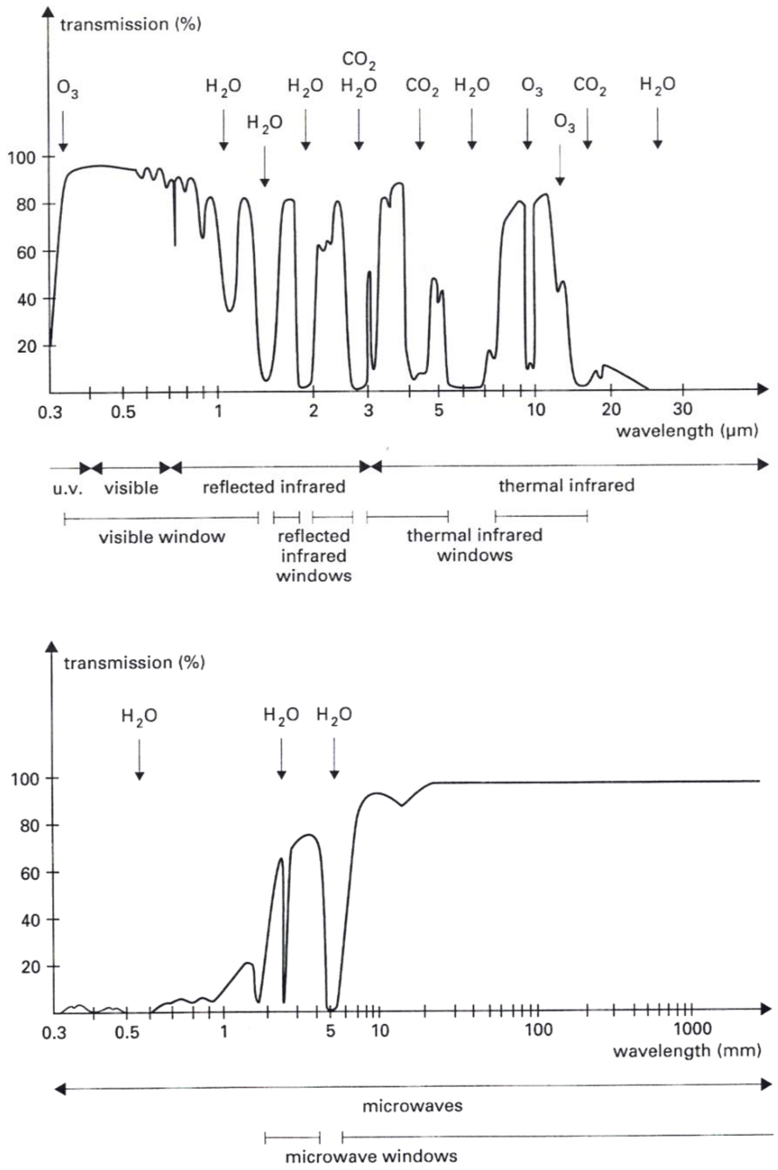
This is **passive** remote sensing where the Sun provides a natural source of illumination.

Active remote sensing involves illuminating the ground from the observing platform in some way, e.g. with radar or lasers.

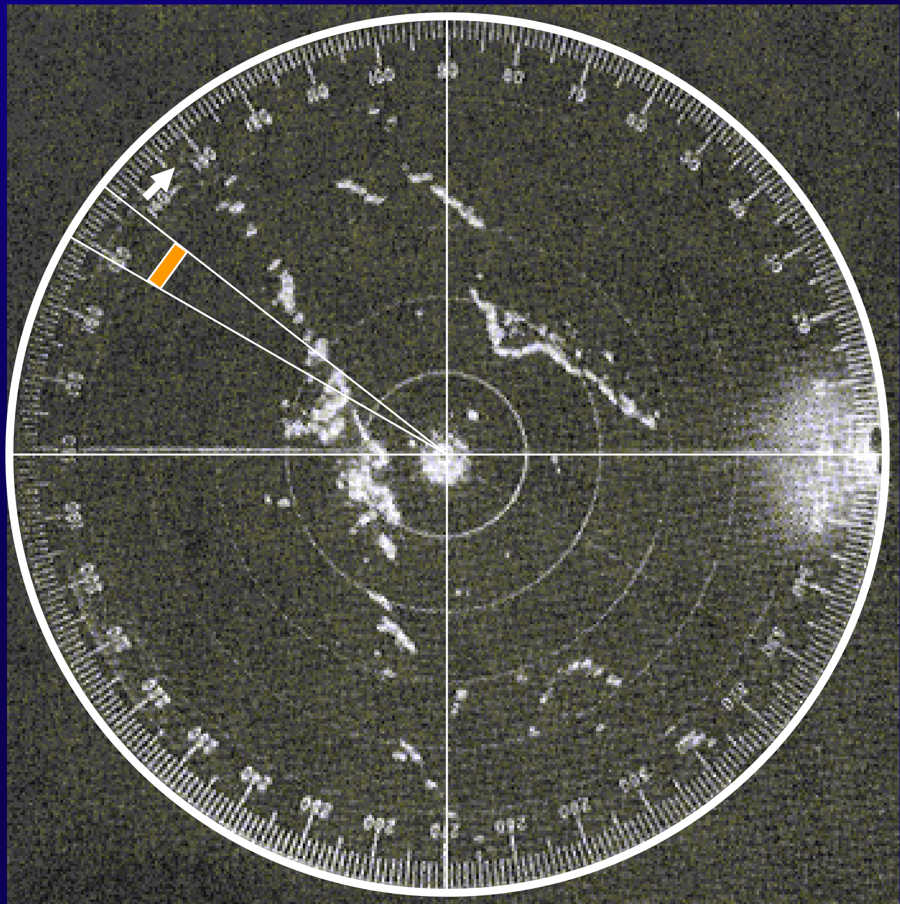
The Electromagnetic Spectrum



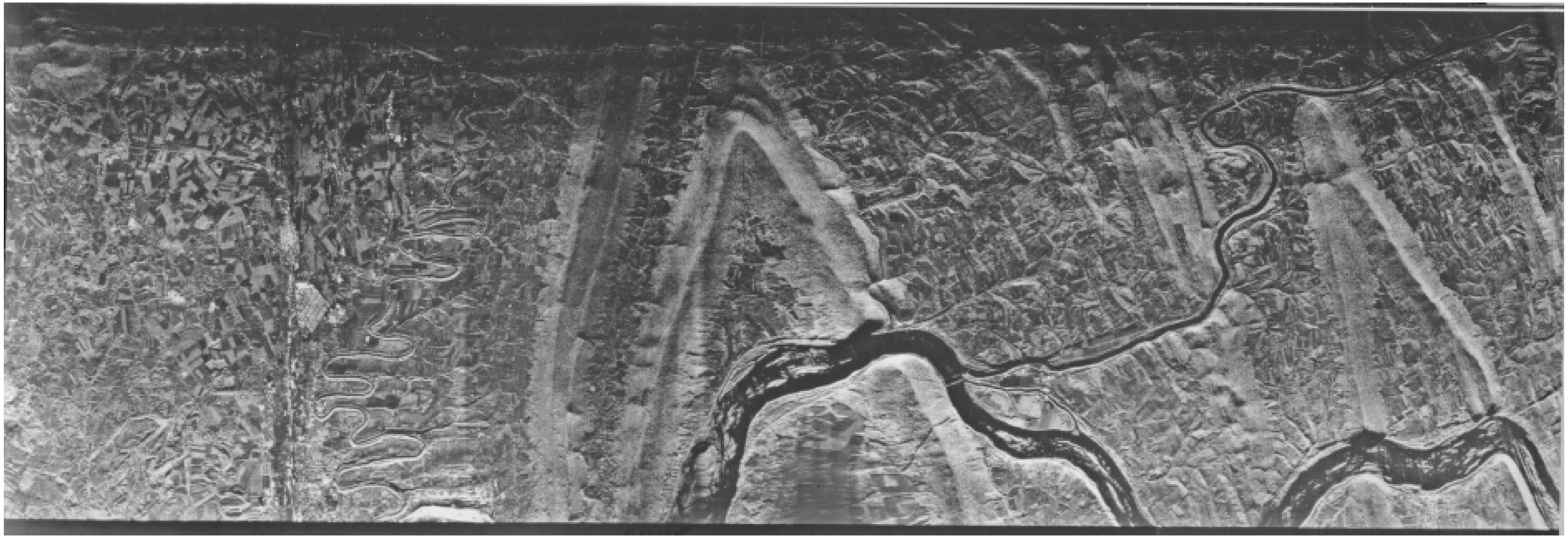
Active Remote Sensing with Microwaves



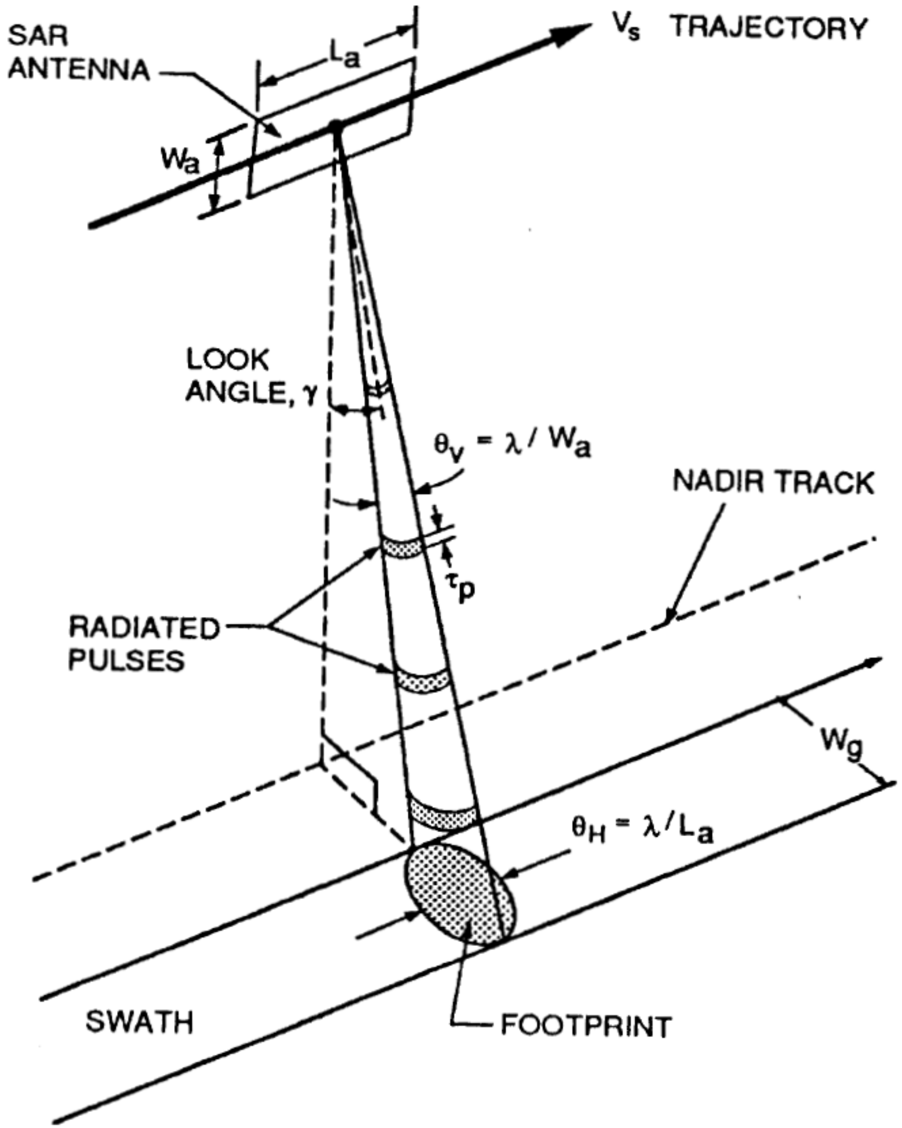
Radar = RAdio Detection And Ranging



Side-Looking Airborne Radar



Side-Looking Airborne Radar



$\theta \sim \lambda / \mathbf{W}$

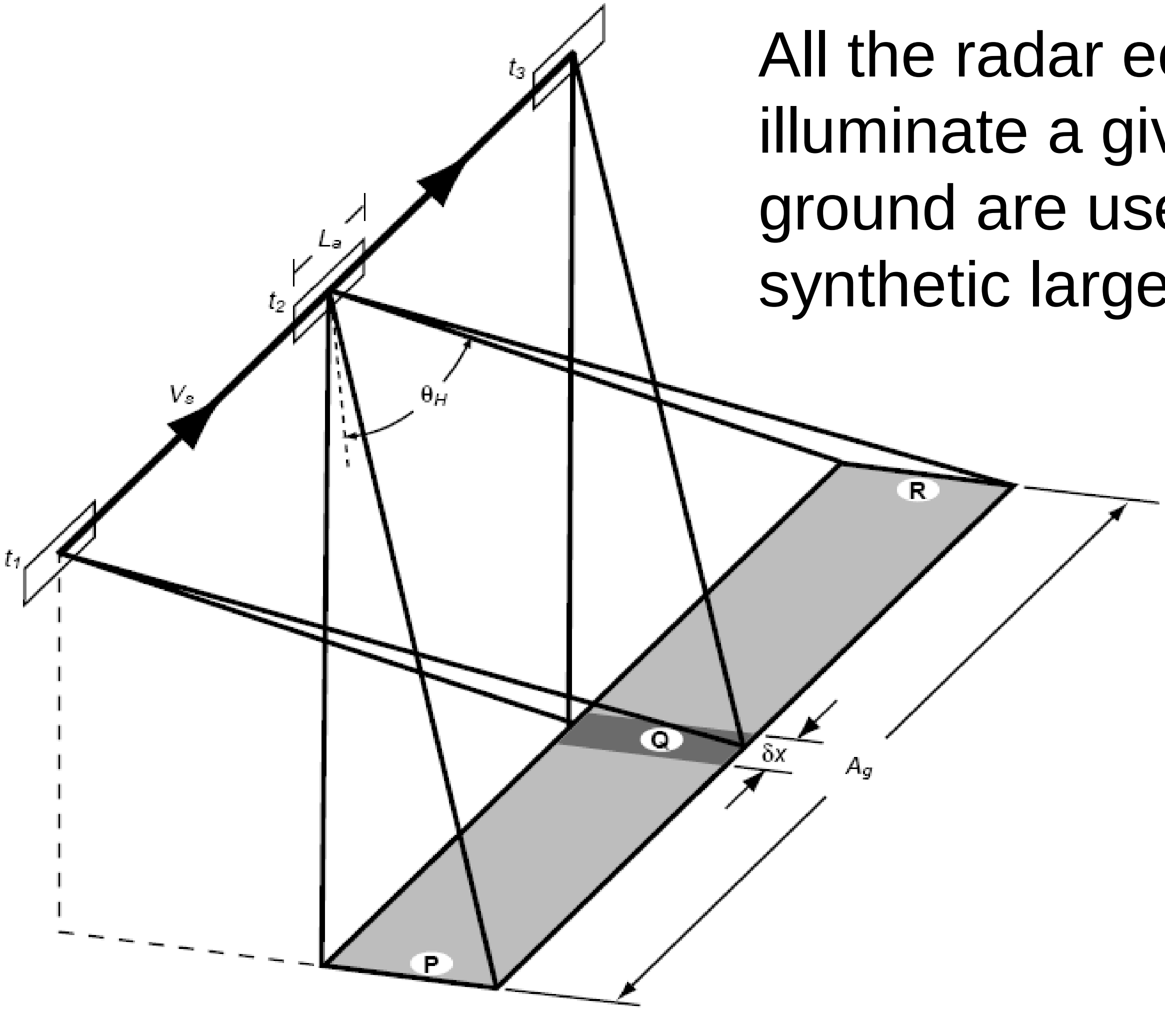
e.g. λ = 0.05 m

W = 10 m

θ ~ 0.005 radians

If at 800 km height, along-track footprint ~ 4 km

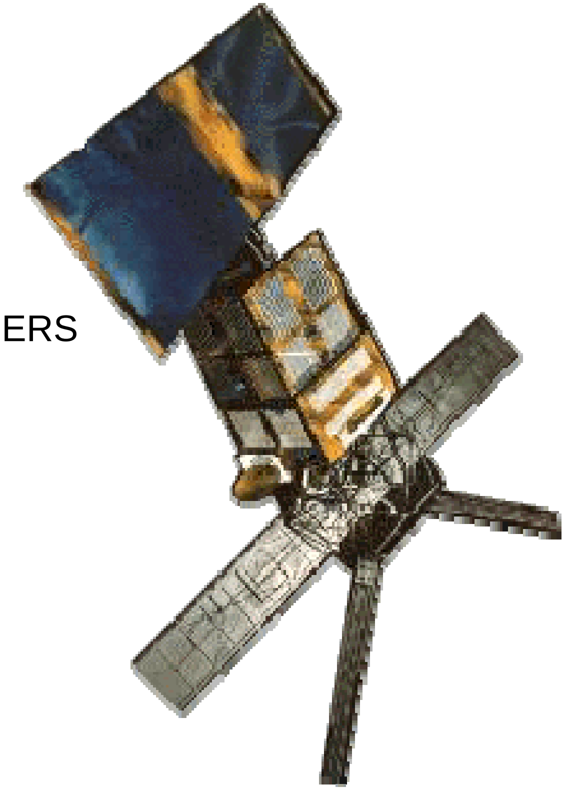
Trick – the Synthetic Aperture

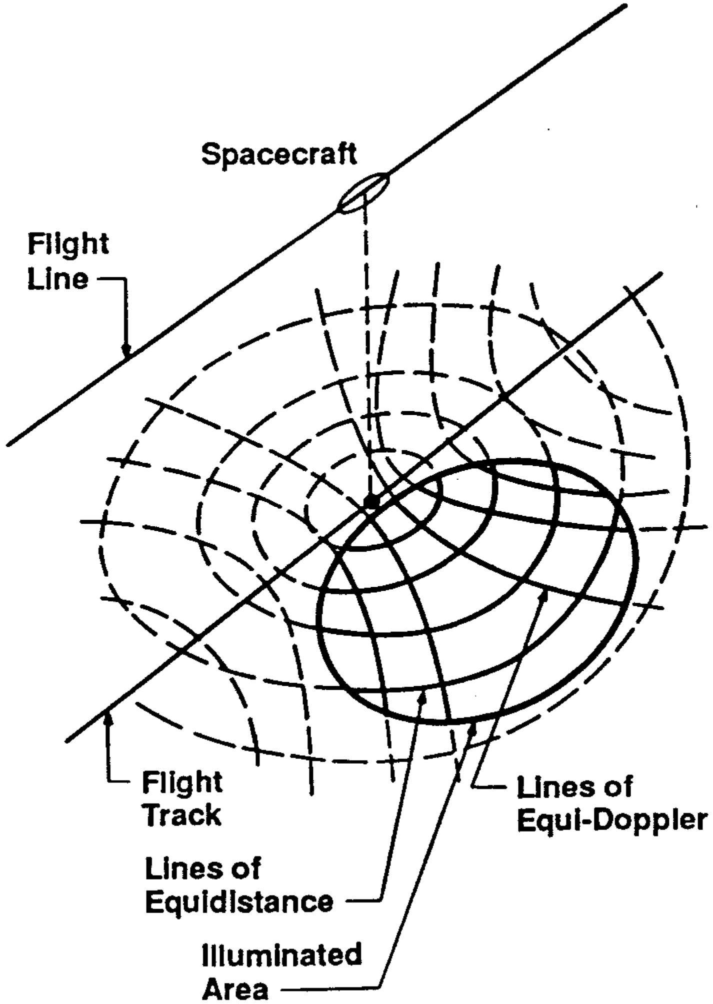


All the radar echoes that illuminate a given patch of ground are used to construct a synthetic larger antenna

Synthetic Aperture Radar (SAR)

ERS



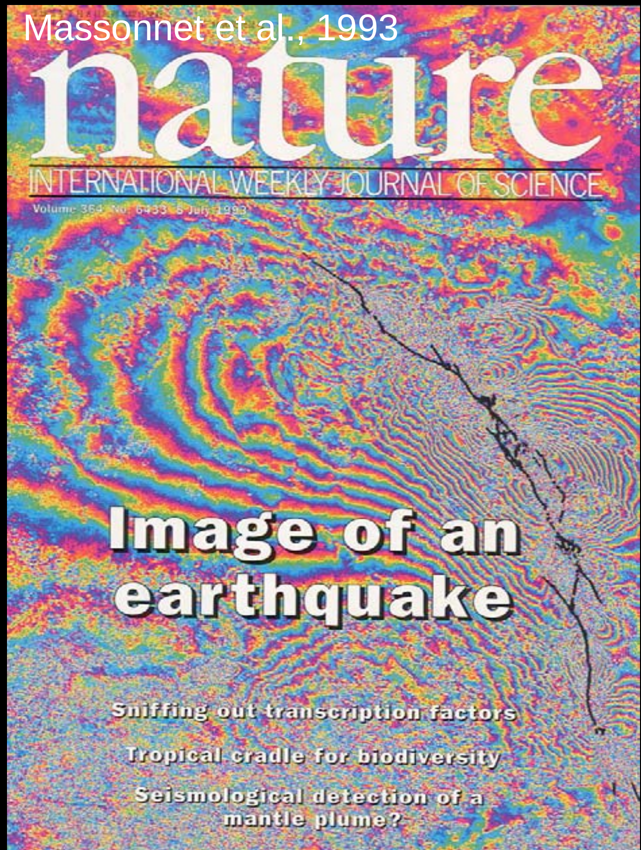


A SAR makes use of measurements of the range and Doppler shift of the radar returns to locate ground points. The signals from many returns are analysed together to image ground elements ~5x20m in size, much smaller than would be possible with a stationary antenna of the same size - hence the Synthetic Aperture.

InSAR – how it works

- Actively illuminate ground with radar waves.
- Operates day and night, can see through clouds
- ERS-1 (1991): very stable orbits and pointing ⇨ InSAR
- Followed by ERS-2 (1995) and Envisat (2003) for ~ 17 year time series

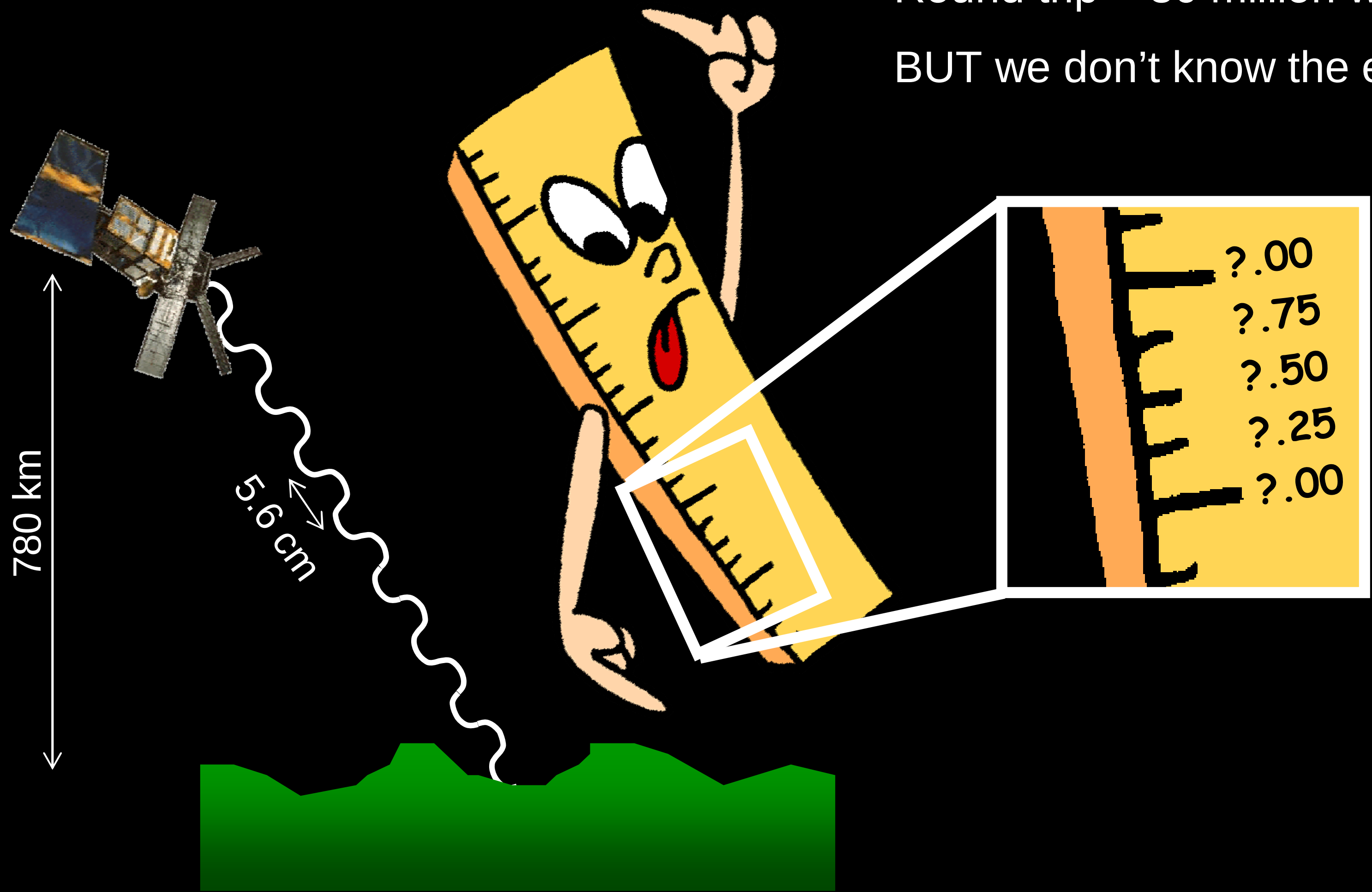
Massonnet et al., 1993



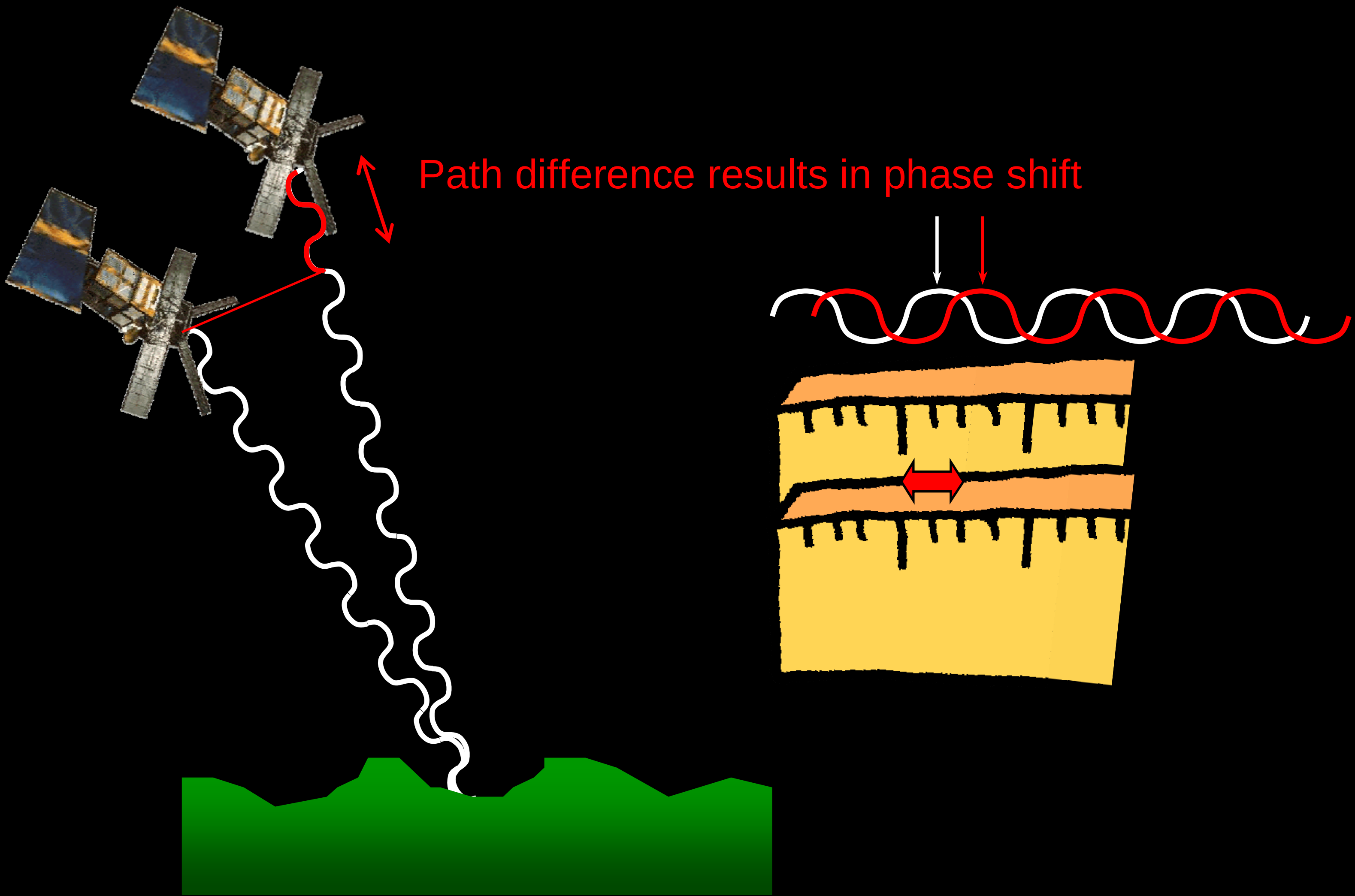
InSAR – how it works

Round trip ~ 30 million wavelengths

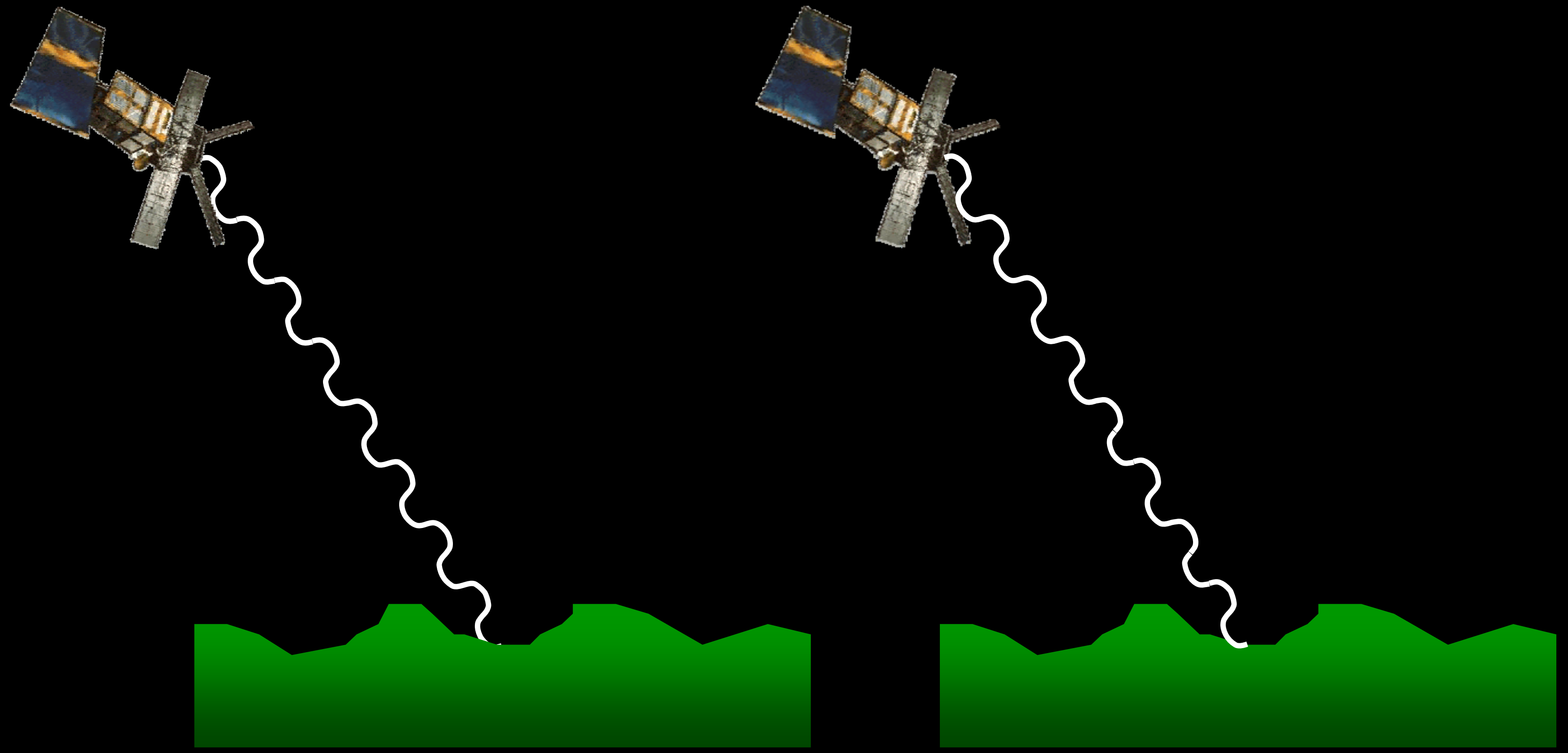
BUT we don't know the exact number



InSAR – how it works



InSAR – how it works



InSAR – how it works

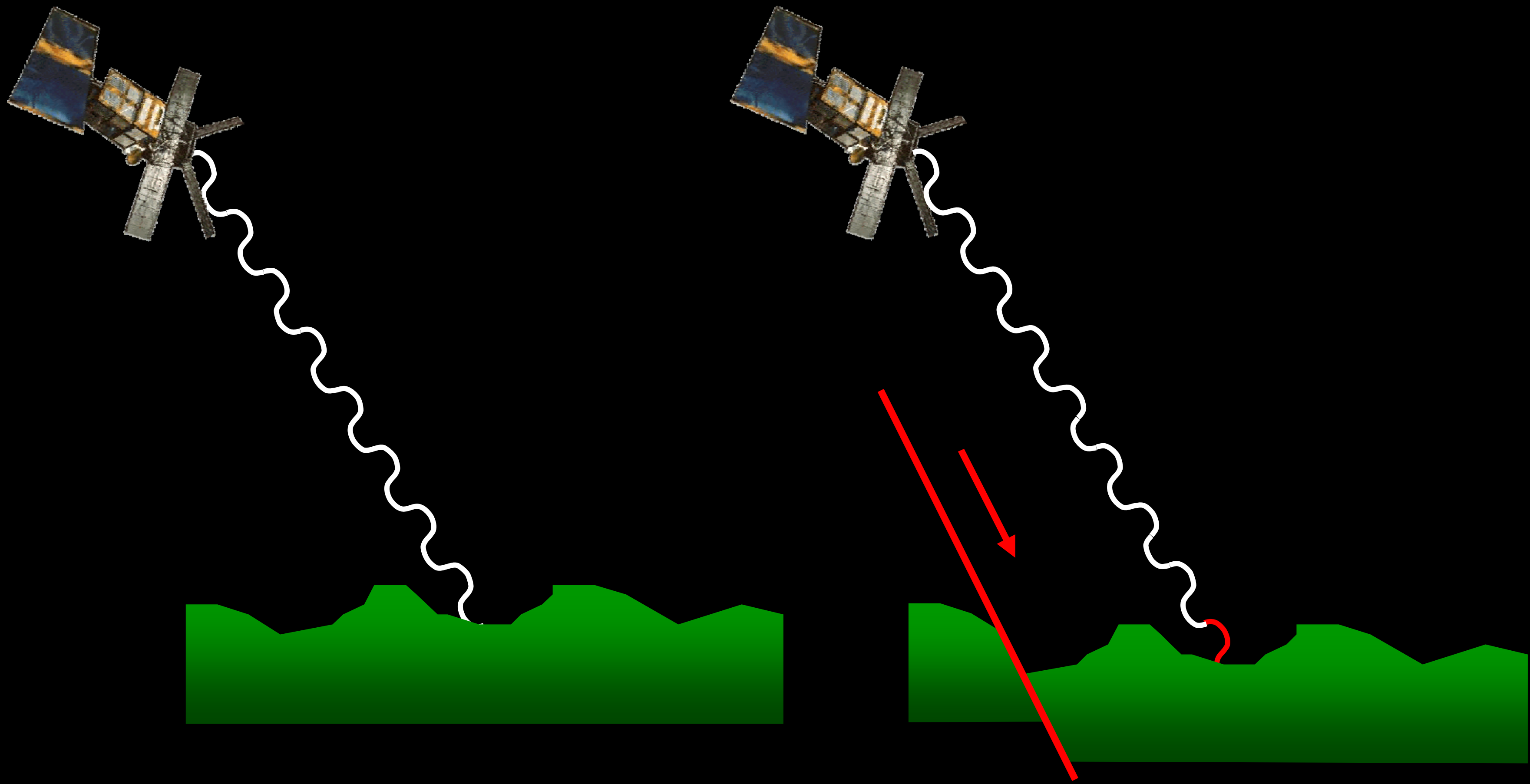
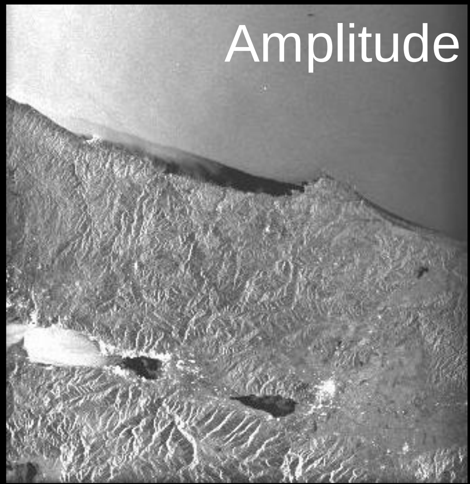
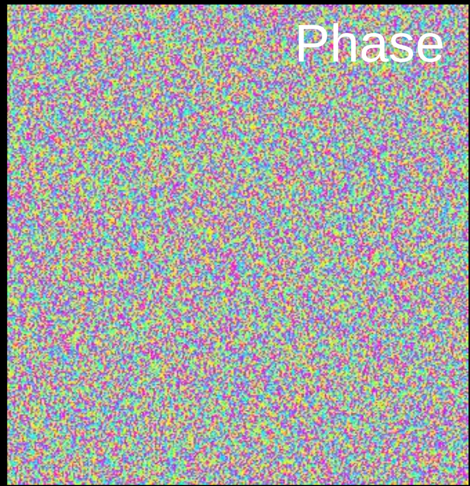
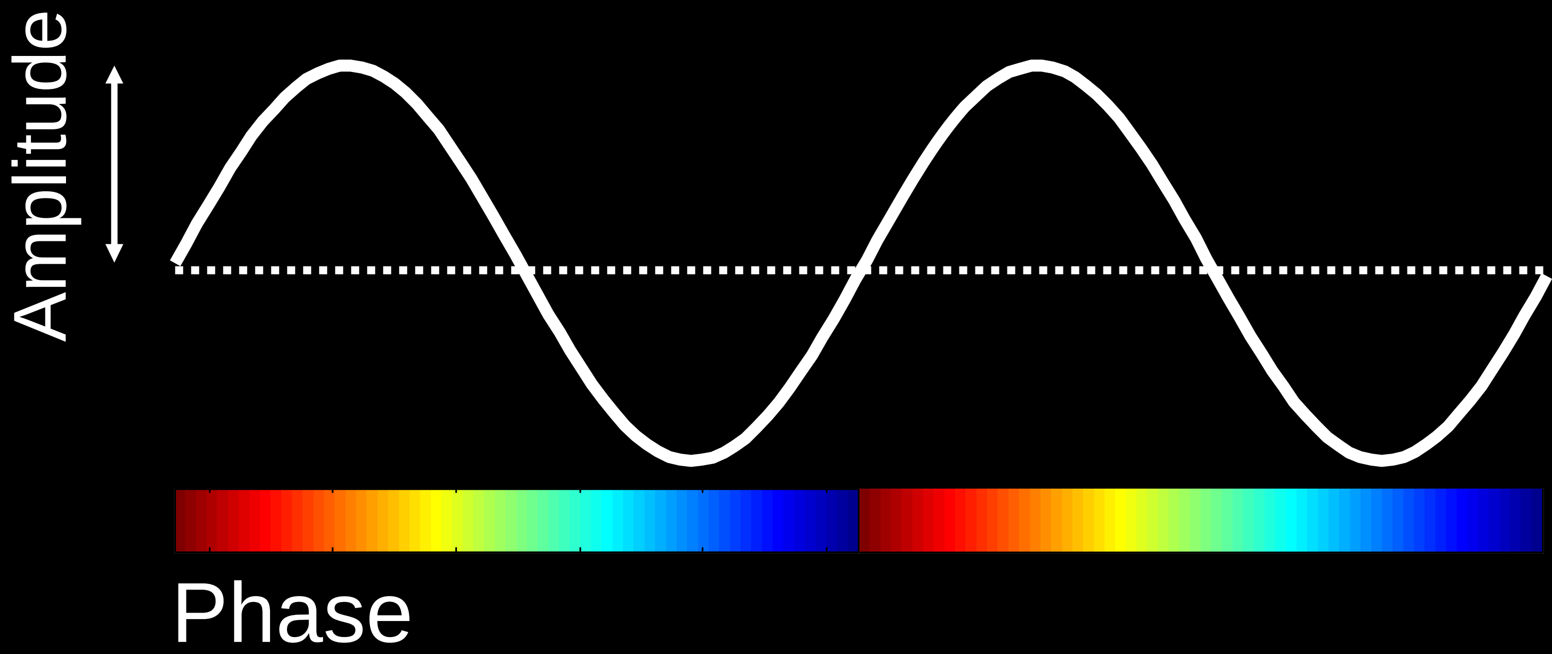


Image A - 12 August 1999







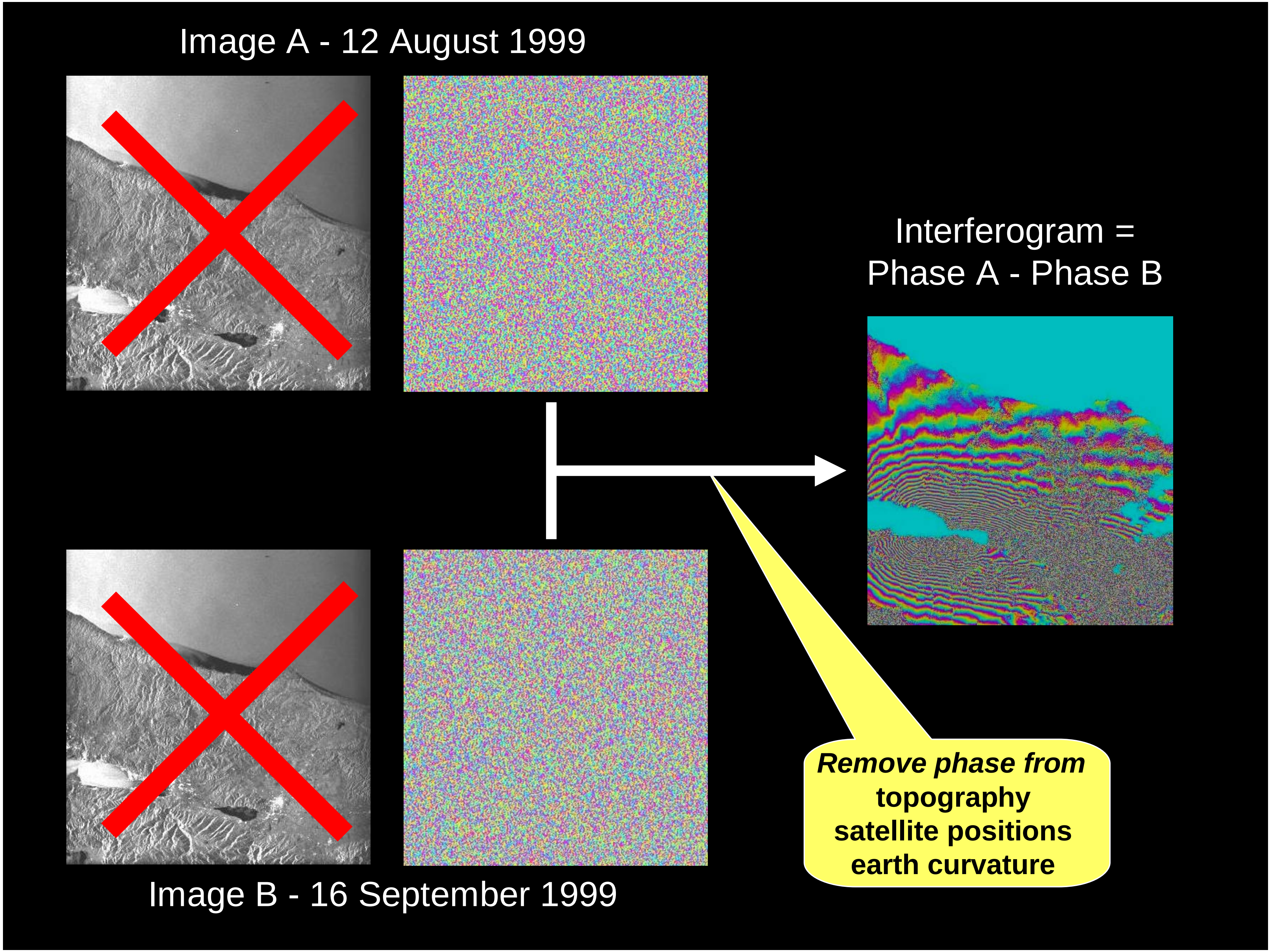
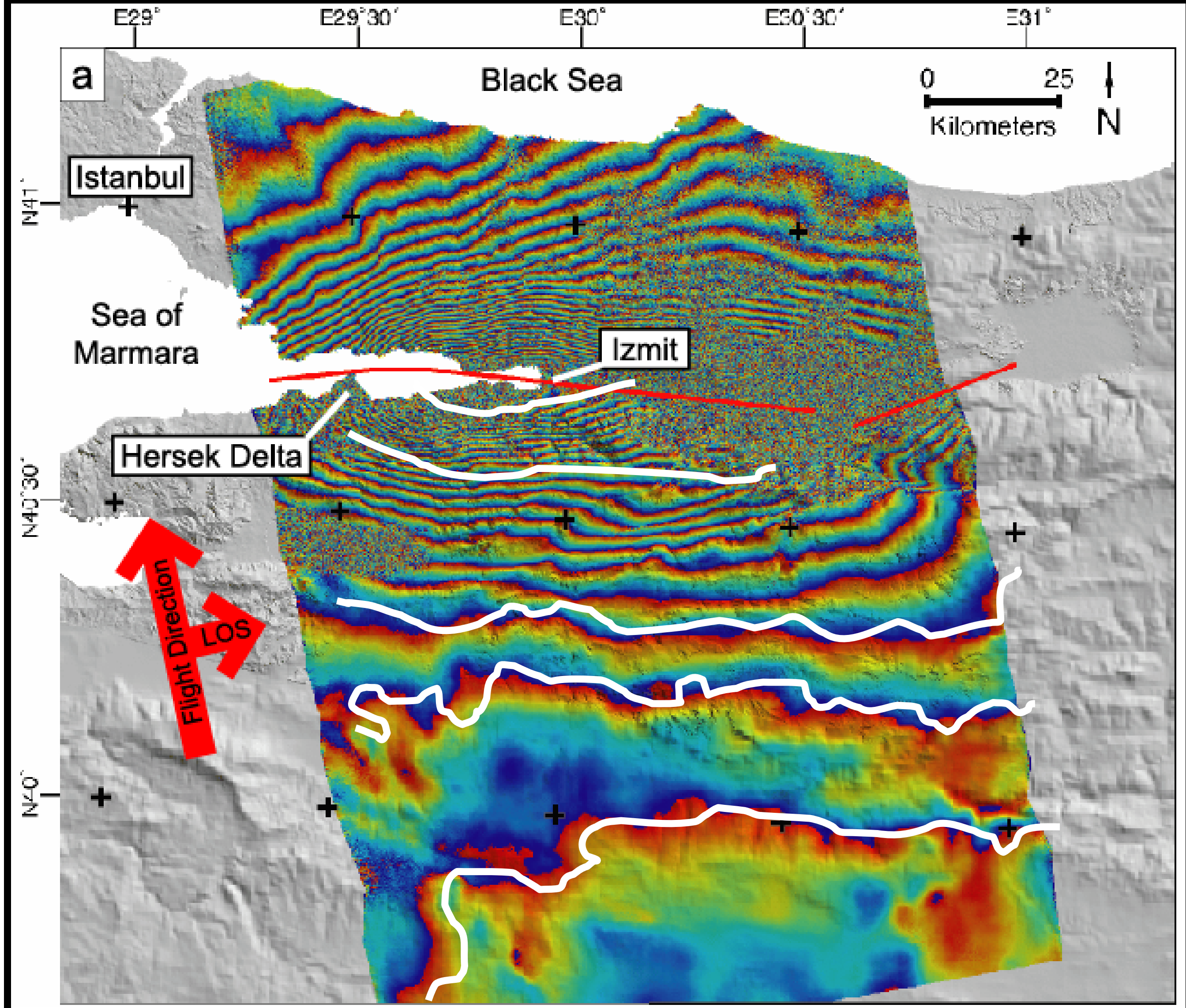


Image A - 12 August 1999
Interferogram =
Phase A - Phase B
Remove phase from
topography
satellite positions
earth curvature
Image B - 16 September 1999



(-20) 567 mm range decrease

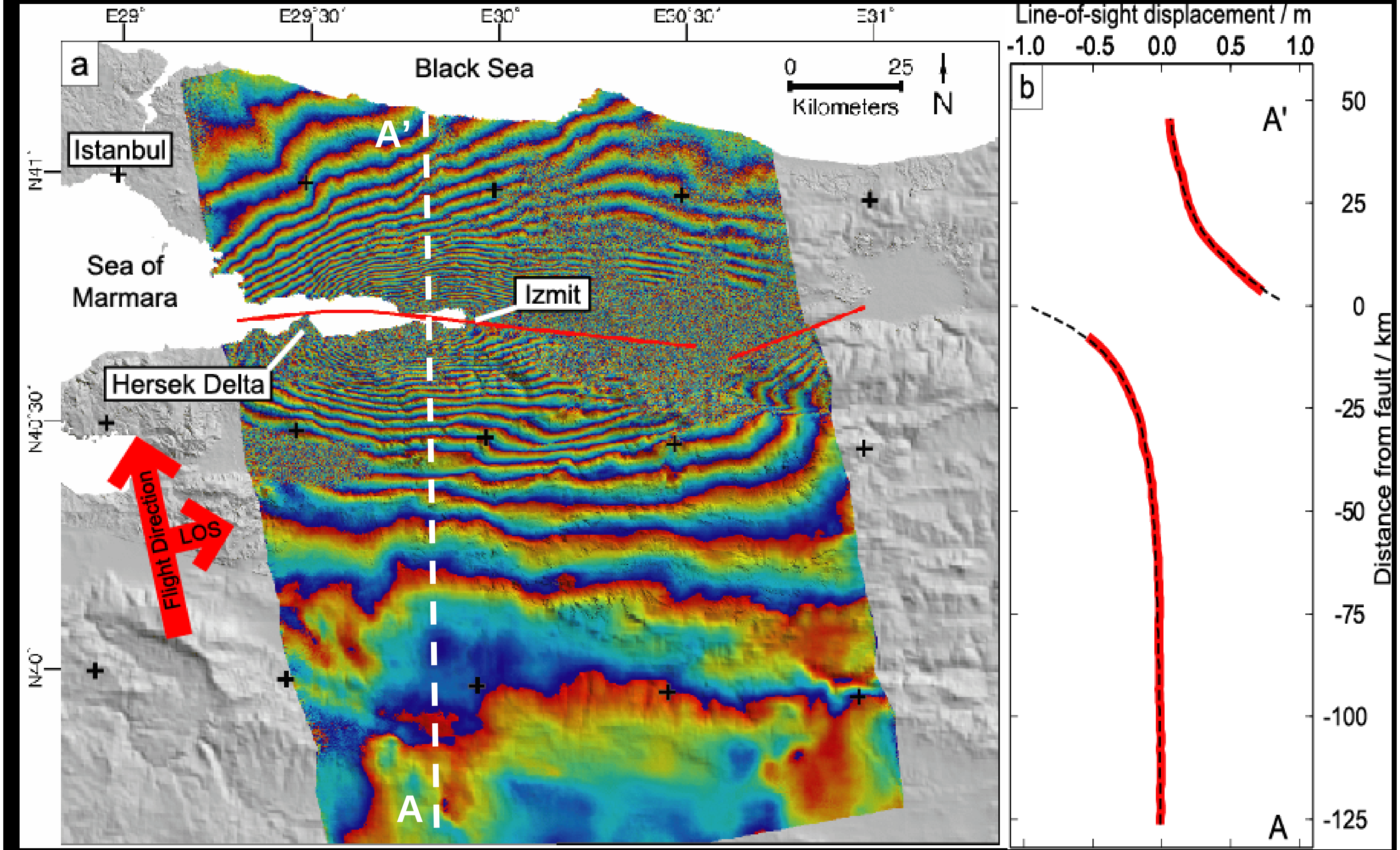
(-10) 283 mm range decrease

(-2) 57 mm range decrease

(-1) 28 mm range decrease

(0) 0 mm range change

17 August 1999, Izmit earthquake (Turkey)



17 August 1999, Izmit earthquake (Turkey)

Components of interferometric phase

$$\Delta\phi_{int} = \Delta\phi_{geom} + \Delta\phi_{topo} + \Delta\phi_{atm} + \Delta\phi_{noise} + \Delta\phi_{def}$$

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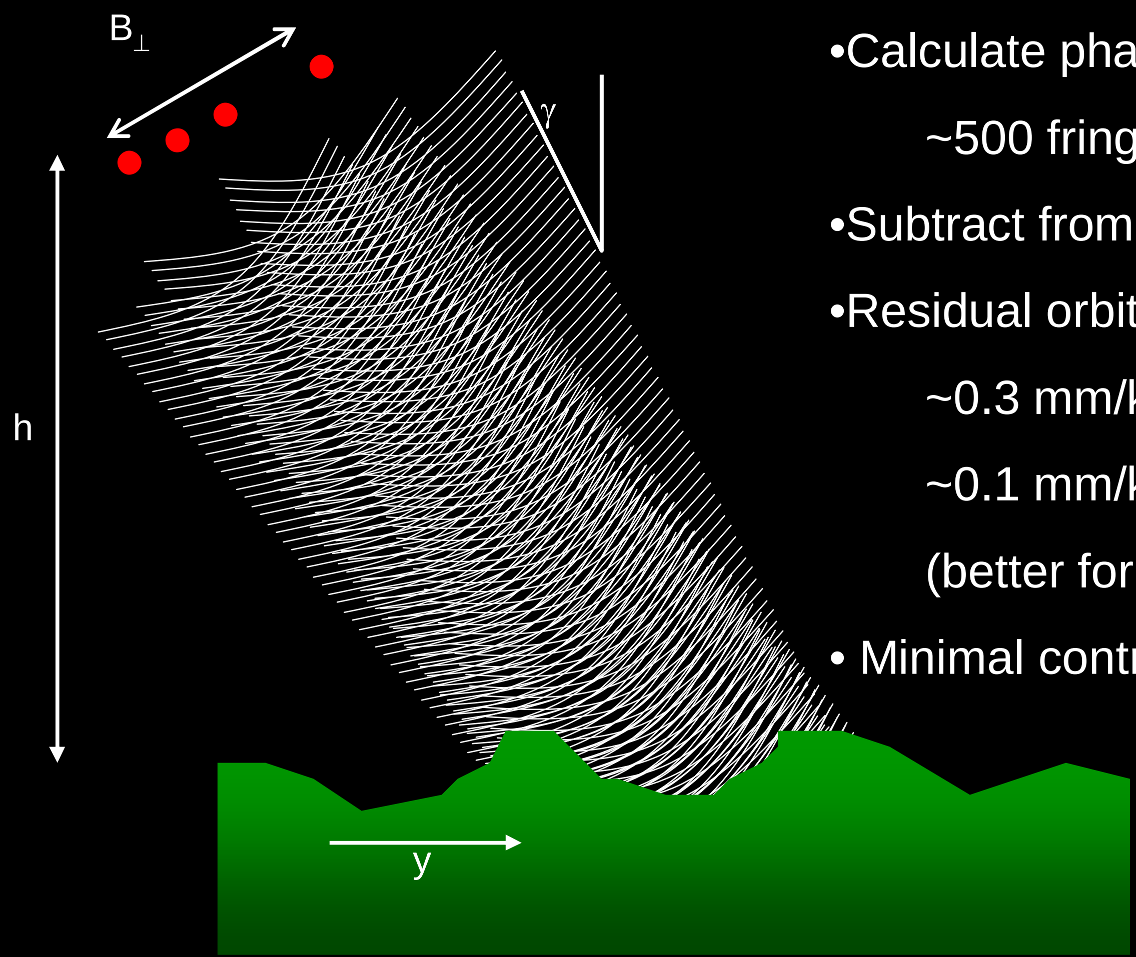

- Calculate phase ramp from satellite orbits
  - ~500 fringes across typical frame
- Subtract from interferogram
- Residual orbital errors:
  - ~0.3 mm/km (north, ERS)
  - ~0.1 mm/km (east, ERS)
  - (better for Envisat)
- Minimal control on v. long wavelength

Components of interferometric phase

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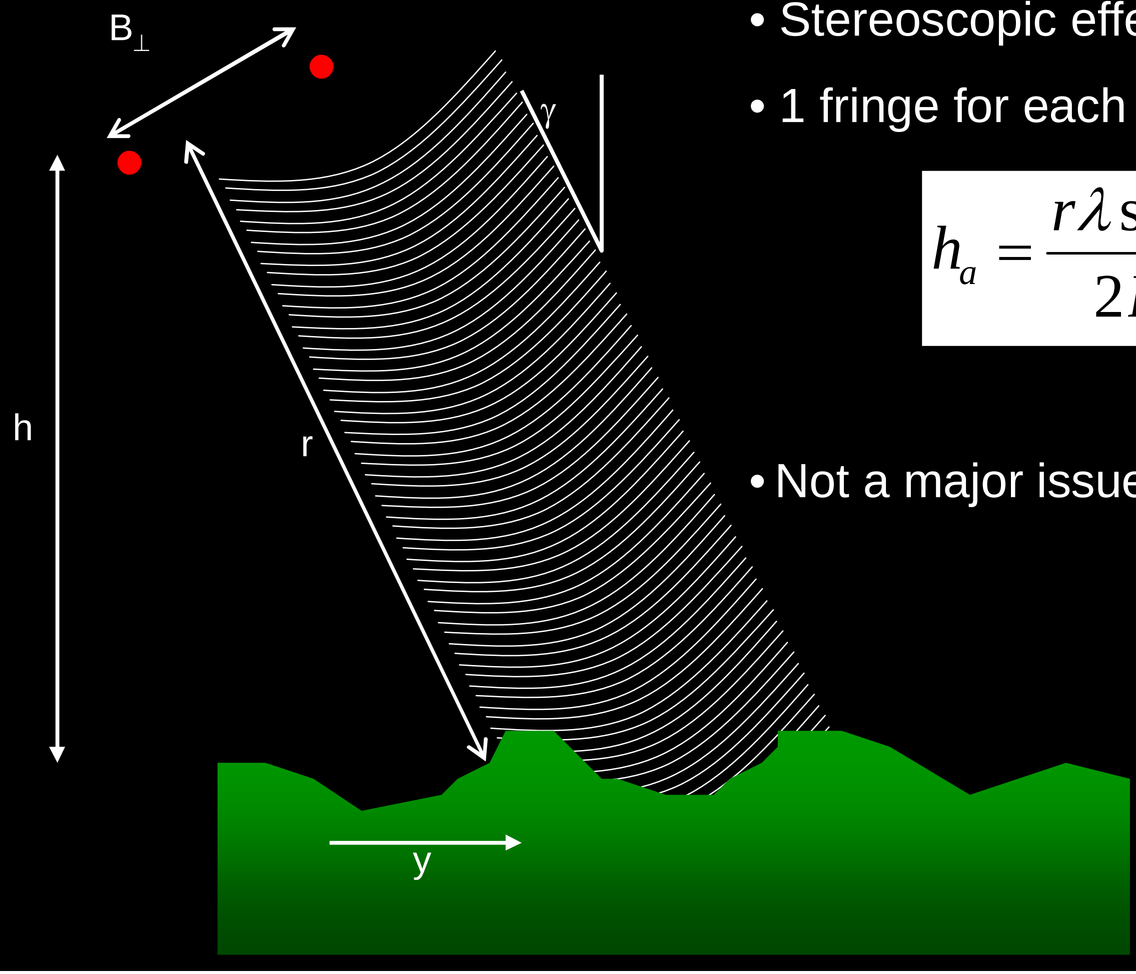


- Stereoscopic effect ⇒ topographic fringes
- 1 fringe for each change in elevation h_a

$$h_a = \frac{r\lambda\sin\gamma}{2B_\perp} \approx \frac{10{,}000}{B_\perp}$$

- Not a major issue since SRTM

Components of interferometric phase

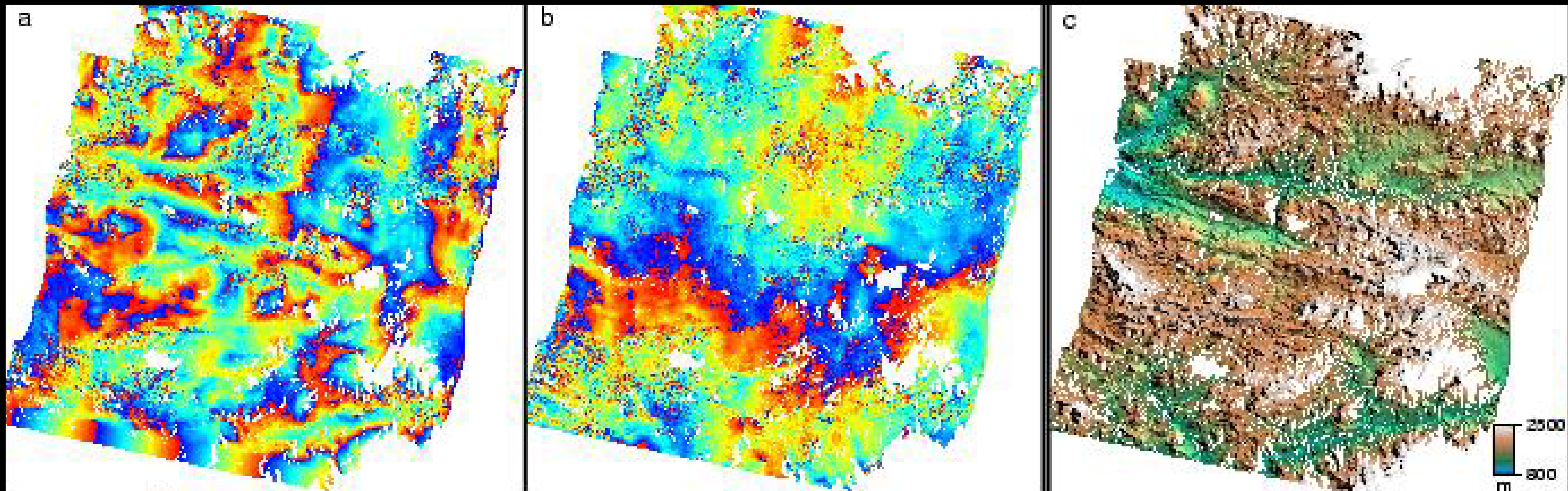
$$\Delta\phi_{int} = \Delta\phi_{geom} + \Delta\phi_{topo} + \Delta\phi_{atm} + \Delta\phi_{noise} + \Delta\phi_{def}$$

A foggy morning,
near ancient Mycenae,
Greece

Components of interferometric phase

$$\Delta\phi_{int} = \Delta\phi_{geom} + \Delta\phi_{topo} + \Delta\phi_{atm} + \Delta\phi_{noise} + \Delta\phi_{def}$$

Layered atmosphere

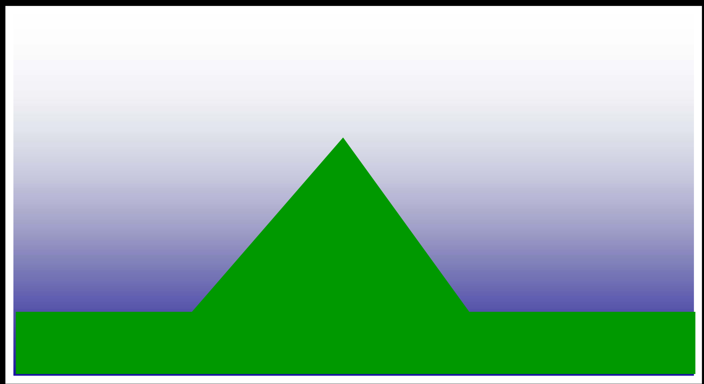


29/8/1995 to 29/7/1997 | 30/8/1995 to 29/7/1997 | Topography

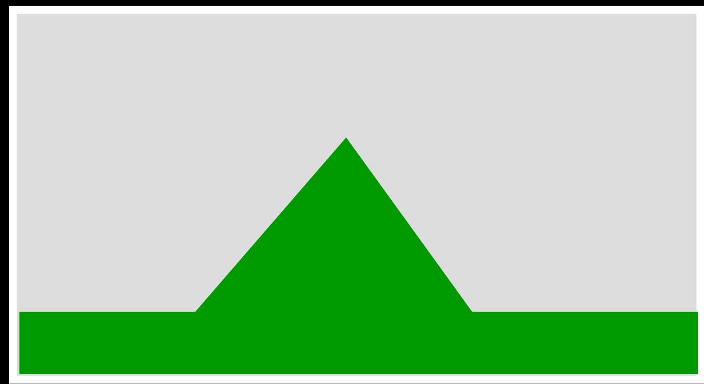
Components of interferometric phase

$$\Delta\phi_{\text{int}} = \Delta\phi_{\text{geom}} + \Delta\phi_{\text{topo}} + \Delta\phi_{\text{atm}} + \Delta\phi_{\text{noise}} + \Delta\phi_{\text{def}}$$

Layered atmosphere



Pass 1

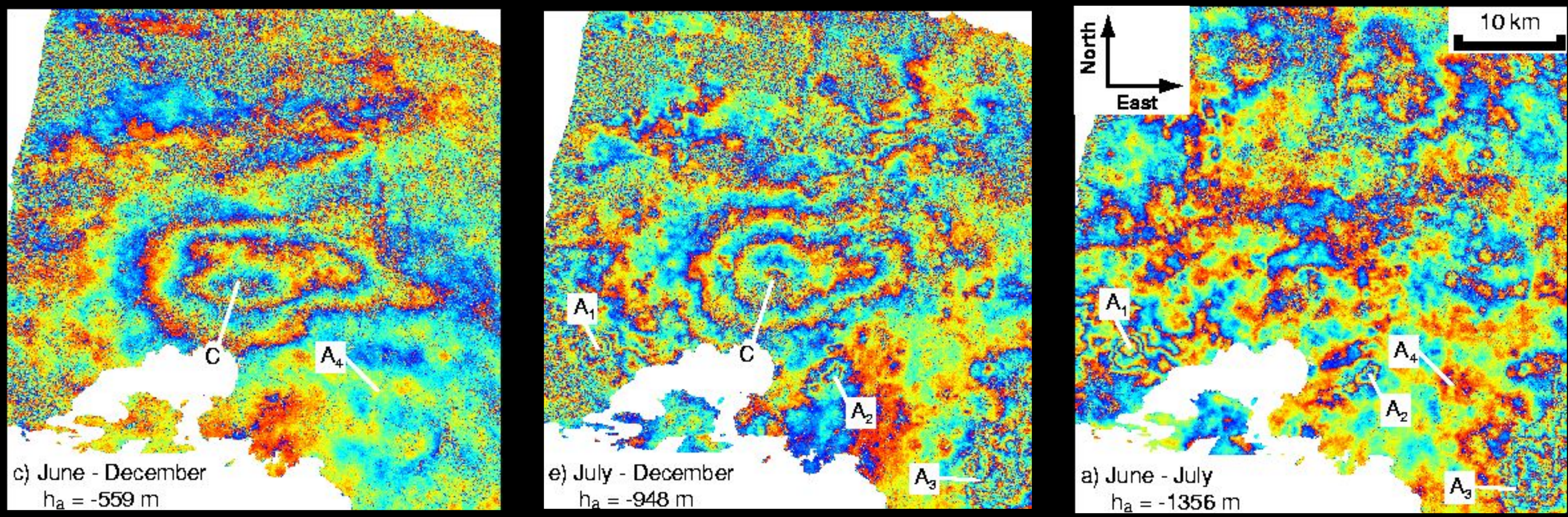


Pass 2

Components of interferometric phase

$$\Delta\phi_{int} = \Delta\phi_{geom} + \Delta\phi_{topo} + \Delta\phi_{atm} + \Delta\phi_{noise} + \Delta\phi_{def}$$

Turbulent atmosphere



June to December   July to December   June to July

Athens Earthquake – September 1999

Components of interferometric phase

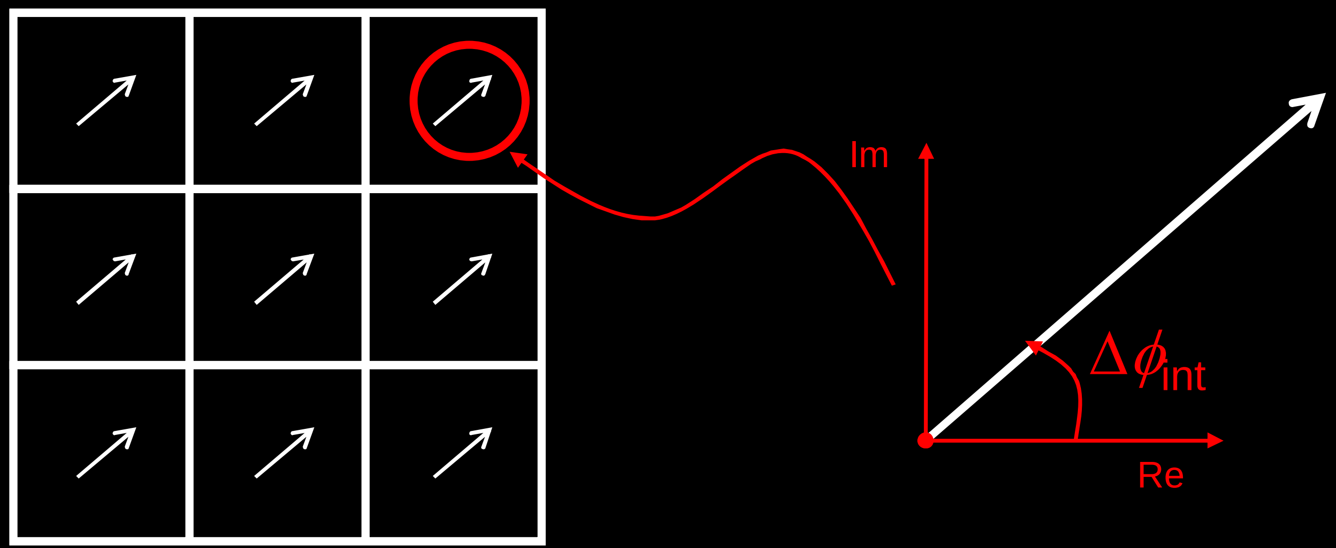
$$\Delta\phi_{int} = \Delta\phi_{geom} + \Delta\phi_{topo} + \Delta\phi_{atm} + \Delta\phi_{noise} + \Delta\phi_{def}$$

- Size of $\Delta\phi_{atm}$ (at sea level) ~ ± 10 cm
- Methods for dealing with $\Delta\phi_{atm}$
  - Ignore (most common)
  - Quantify
  - Model based on other observations (e.g. GPS, meteorology…)
  - Increase SNR by stacking or time series analysis

Components of interferometric phase

$$\Delta\phi_{int} = \Delta\phi_{geom} + \Delta\phi_{topo} + \Delta\phi_{atm} + \Delta\phi_{noise} + \Delta\phi_{def}$$

- Biggest source of noise is due to changing ground surface
- *Coherence* is convenient measure



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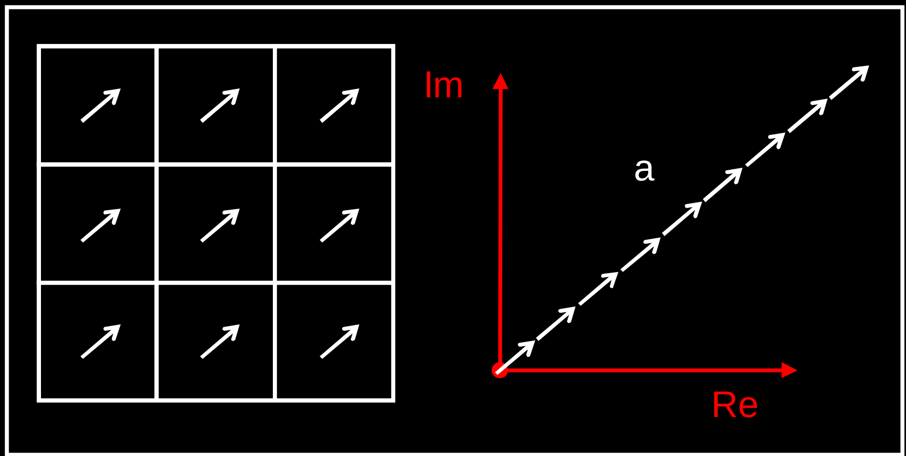
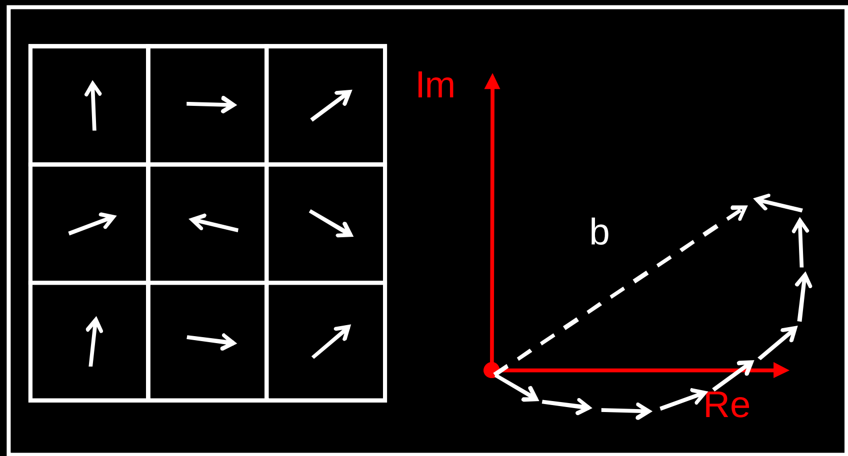
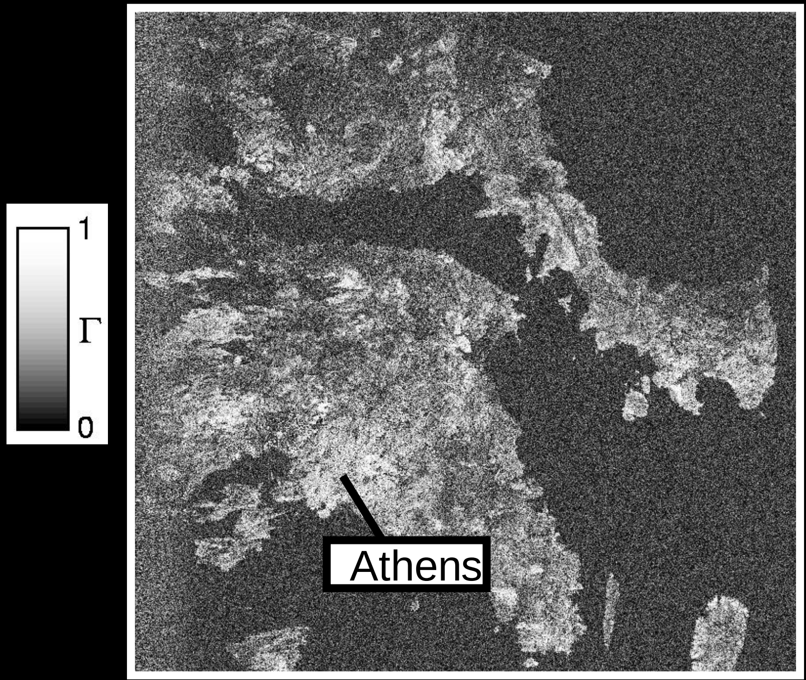




Coherence = b / a

Components of interferometric phase

$$\Delta\phi_{\text{int}} = \Delta\phi_{\text{geom}} + \Delta\phi_{\text{topo}} + \Delta\phi_{\text{atm}} + \Delta\phi_{\text{noise}} + \Delta\phi_{\text{def}}$$



Coherent surface types

- Bare Rock
- Buildings esp. towns/cities

- Grassland
- Agricultural fields
- Ice

Incoherent surface types

- Leafy Trees
- Water

Components of interferometric phase

$$\Delta\phi_{int} = \Delta\phi_{geom} + \Delta\phi_{topo} + \Delta\phi_{atm} + \Delta\phi_{noise} + \Delta\phi_{def}$$

1. incoherence

- Changes in the ground cover cause a random phase shift for each pixel
- Large baselines

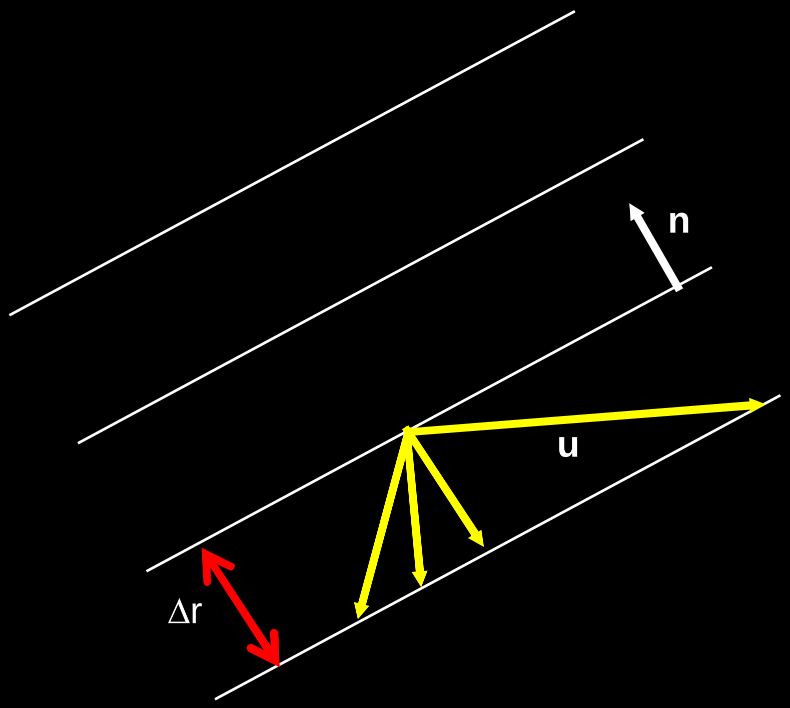
2. Unwrapping errrors

- Phase in interferograms is wrapped (each fringe is 2 π radians).
- Discontinuities or data gaps can cause phase unwrapping errors

Components of interferometric phase

$$\Delta\phi_{int} = \Delta\phi_{geom} + \Delta\phi_{topo} + \Delta\phi_{atm} + \Delta\phi_{noise} + \Delta\phi_{def}$$

InSAR ONLY MEASURES THE COMPONENT OF SURFACE DEFORMATION IN THE SATELLITE'S LINE OF SIGHT



$$\Delta r = - \mathbf{n} . \mathbf{u}$$

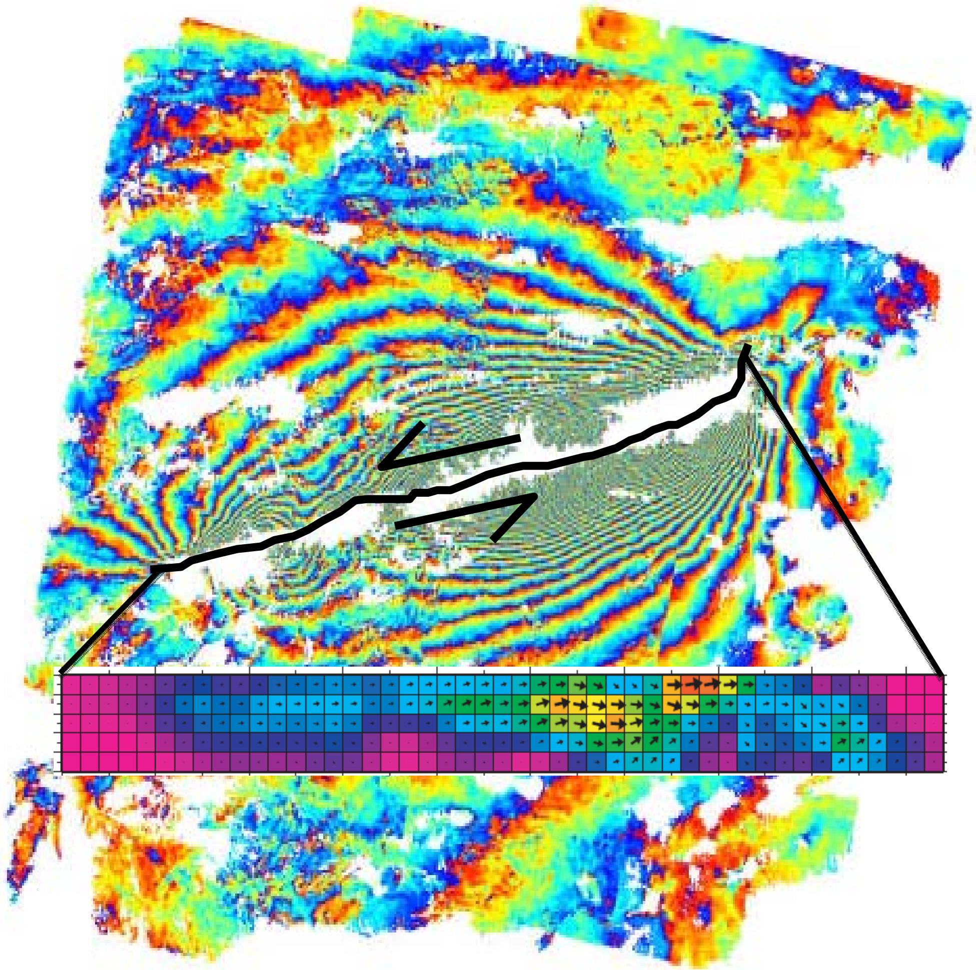
where n is a unit vector pointing from the ground to the satellite

$$\Delta\phi_{def} = (4\pi / \lambda)\, \Delta r$$

i.e. 1 fringe = 28.3 mm l.o.s. deformation for ERS

Earthquakes

1. Coseismic Deformation



Current Capability

- Map deformation fields for most damaging earthquakes.
- Identify responsible faults
- Estimate slip models.
- Assess impact on future hazard .

What could be done?

- Routine analysis of **ALL** damaging earthquakes, c.f. Harvard CMT.
- Real-time assessment of causative fault and likely damage area.
- Near-real time assessment of future hazard (aftershocks + triggered quakes).

Why are we not doing this already?

- Data.
- Method Development.
- Manpower.

Earthquakes

2. Interseismic Strain

Current Capability

- Measure interseismic strain rates on suitable, targeted faults.
- Use these to constrain slip rate and hence assess future hazard.

What could be done?

- Routine measurement of strain across whole regions.
- Assessment of slip rates and relative hazard of multiple faults (including unidentified faults).

Why are we not doing this already?

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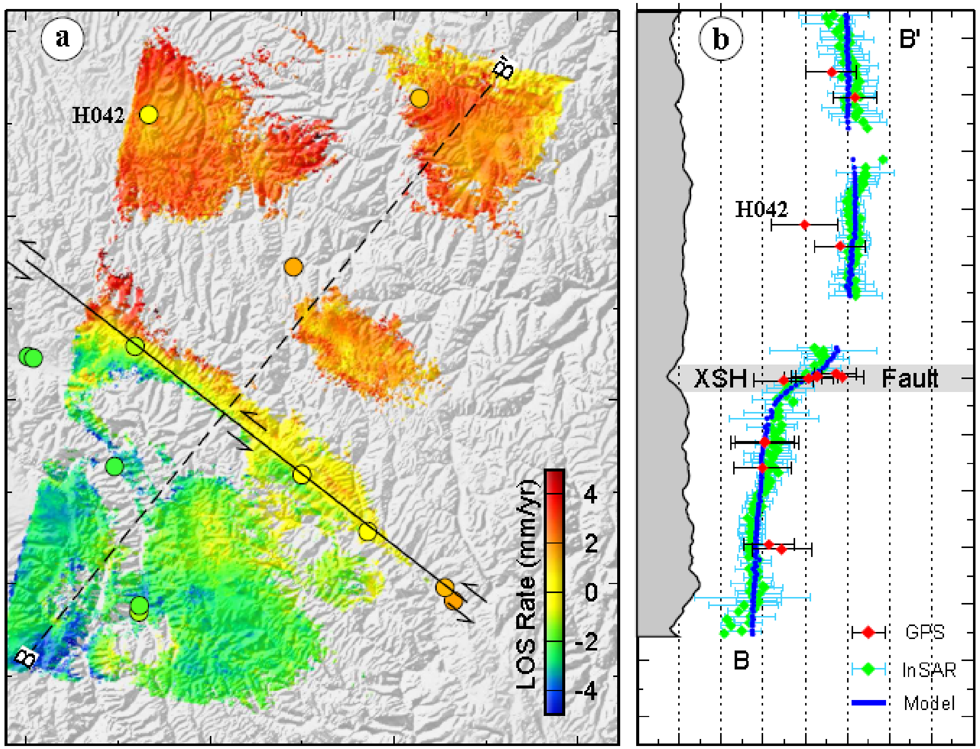
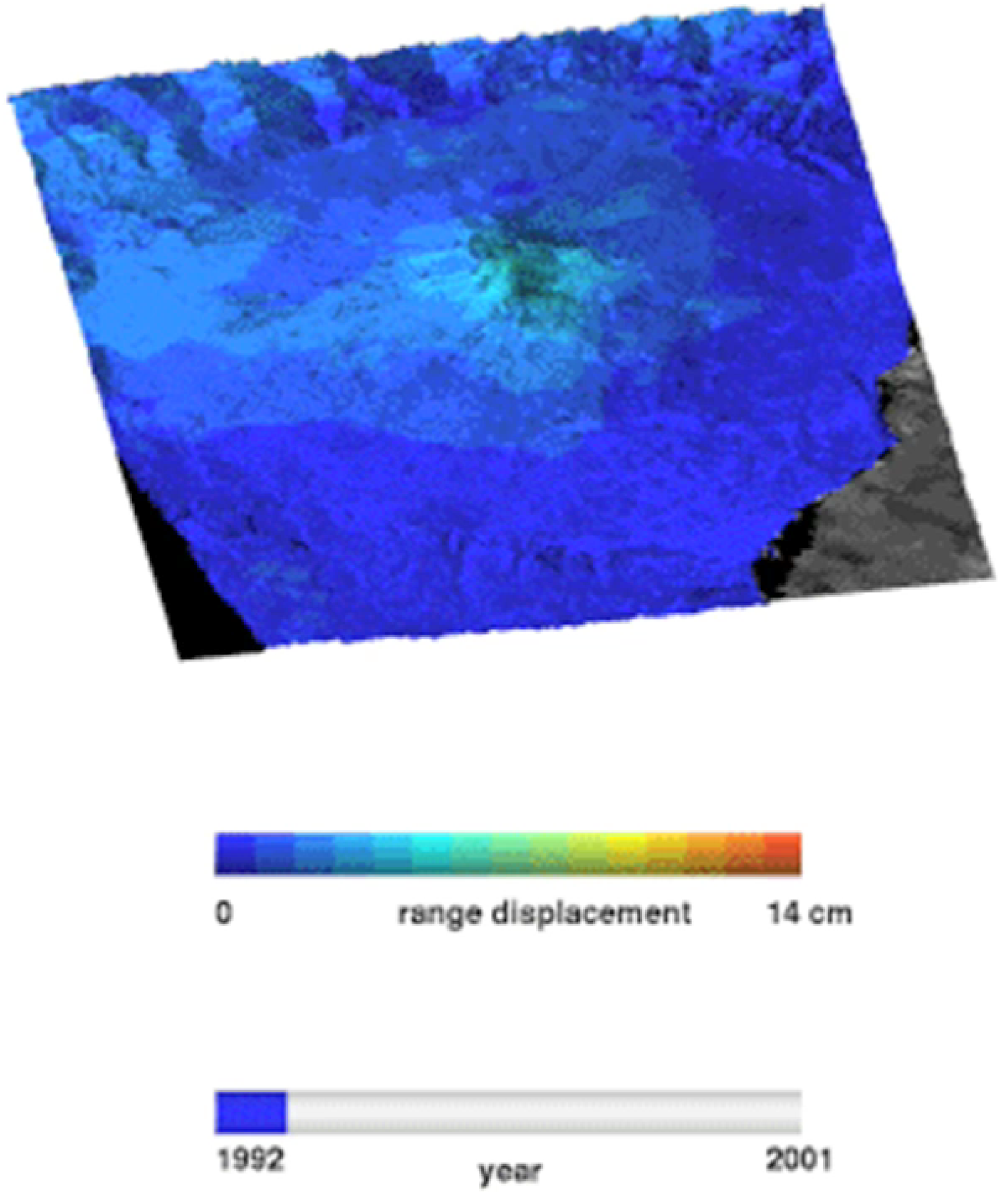


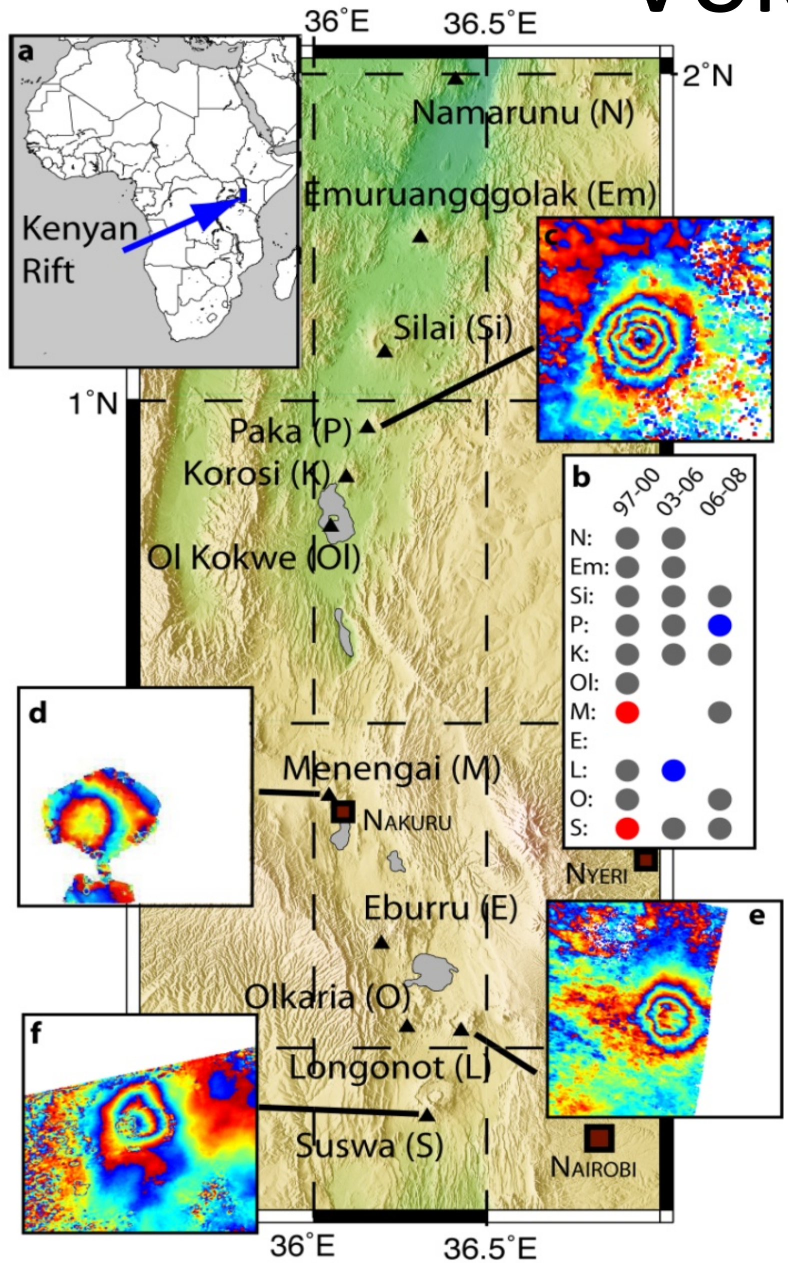
Wang, Wright and Biggs., GRL 2009

Volcanoes



movie

Volcanoes



Biggs, J., Anthony, E.Y., Ebinger, C.J.
Figure 1. biggs_fig1.jpg

Current Capability

- Time-series analysis for suitable, targeted volcanoes

.

- Snapshot regional surveys.
- Integration with other data sets.

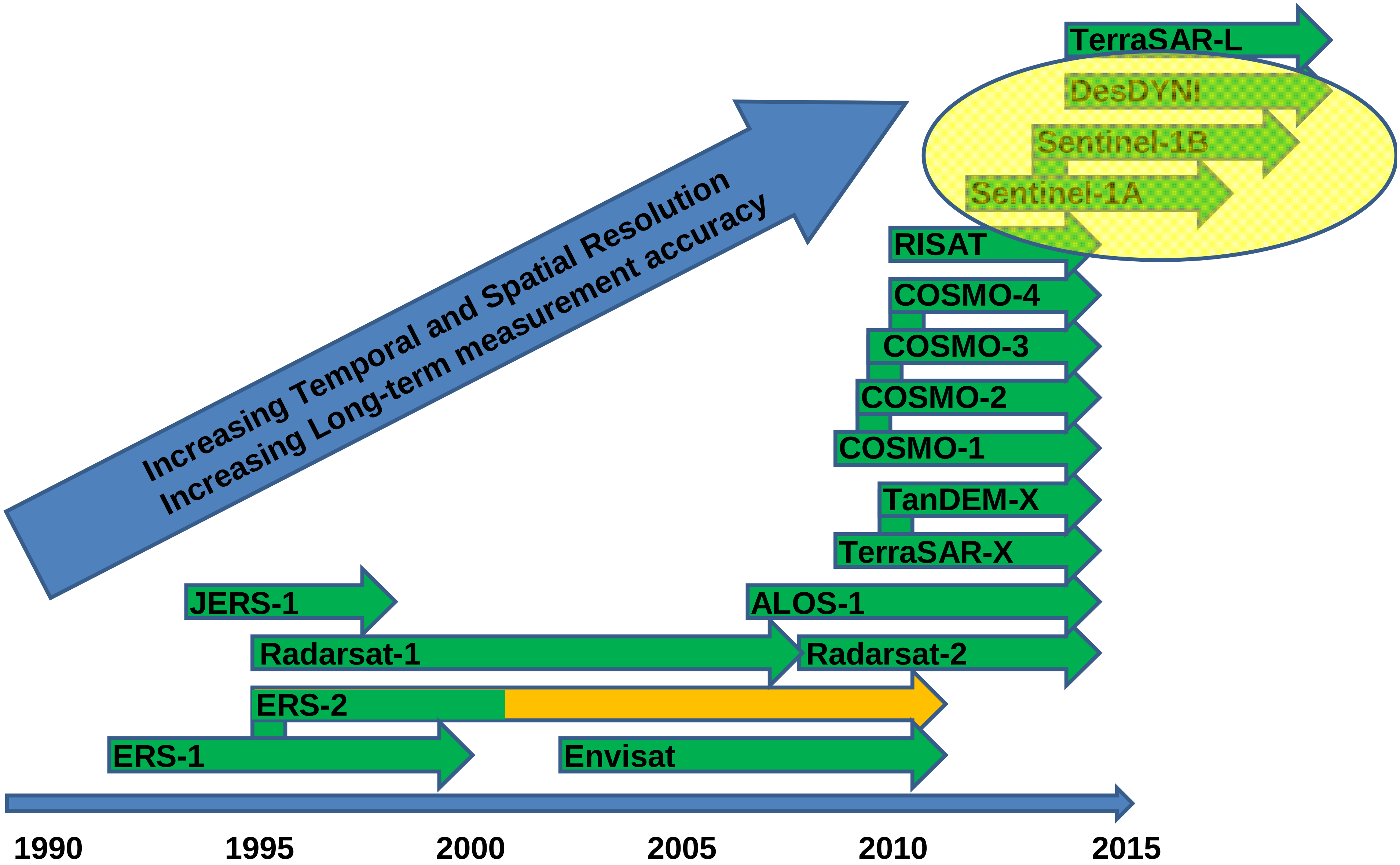
What could be done?

- Routine monitoring of ALL volcanoes worldwide (or in a region).
- Target application of ground monitoring in countries where resources are limited.

Why are we not doing this already?

- Data.
- Method Development.
- Manpower.

Launched or Planned Radar Satellites



The Future

Sentinel-1 (ESA, GMES)

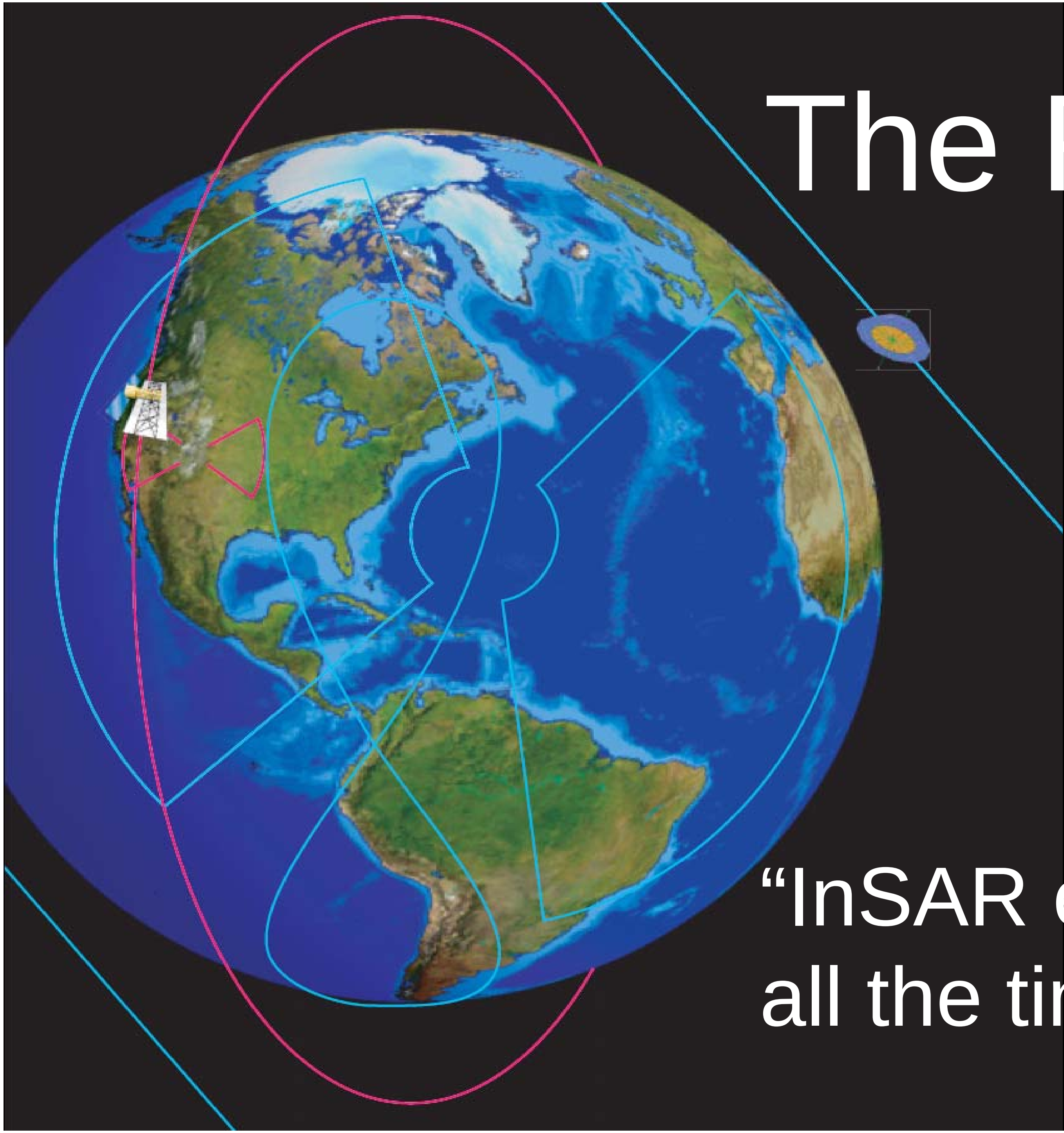
- “Operational” C-band InSAR
- Funded, Launch 2012

The Future

NASA: L-band, InSAR + LiDAR

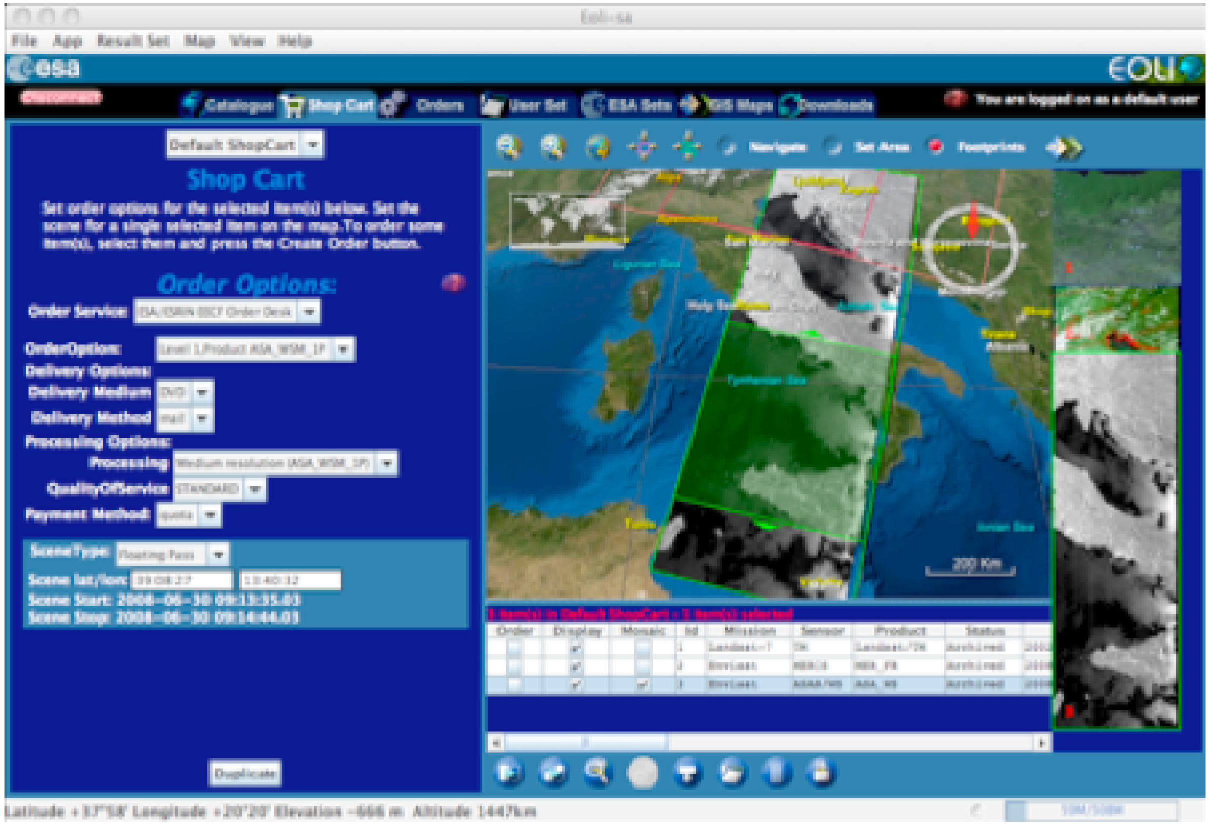
- Funding not yet confirmed
- Proposed launch 2010-2013

The Future



"InSAR everywhere, all the time"

Searching the Data Archive



ENVISAT, ERS, Landsat, IKONOS, DMC, ALOS, SPOT, Kompsat, Proba, JERS IRS, Nimbus, NOAA, SCISAT, SeaStar, Terra/Aqua.

http://earth.esa.int/EOLi/EOLi.html

Select option: ‘connect as anonymous user’

Ordering Data

http://eopi.esa.int/esa/esa?cmd=aodetail&aoname=Cat1

Submit a category 1 proposal to ESA - entitles you to data at reproduction costs only

Category 1: research and applications development use in support of the mission objectives, including research on long term issues of Earth system science…

Data Costs

For Envisat/ERS. per scene (~100km x 100km)
Archive - 25 €
Programming - 80 €
But costs may be waved for scientists from developing countries

Conclusions

- InSAR is a powerful, low-cost tool for monitoring Earth deformation
- Capability improving continuously (smaller rates, bigger areas…)
- Future missions and method development will ensure InSAR is a standard technique

Using the predictions and research of leading experts it portrays nature's rarest and most cataclysmic event...

SUPERVOLCANO

bbc.co.uk/supervolcano


SUPERVOLCANO
bbc.co.uk/supervolcano